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THE BLOCK DISPLACEMENT METHOD FIELD DEMONSTRATION AND SPECIFICATIONS

by

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The Block Displacement technique has been developed as a remedial action method for isolating large tracks of ground contaminated by hazardous waste. The technique places a low permeability barrier around and under a large block of contaminated earth.

The Block Displacement process is composed of separate bottom barrier and perimeter barrier construction processes. The bottom barrier construction is accomplished by propagating horizontal separations from a series of injection wells. A soil-bentonite slurry is pumped into these wells at low pressure opening the separation and forming a barrier. In the process the ground is displaced upward by an amount corresponding to the thickness of the final barrier placed. The perimeter barrier is constructed by one of various means including slurry wall, jet grouting, or drill notch and blast. The perimeter barrier is constructed prior to the bottom if necessary to induce a favorable in-situ stress state.

The technique was demonstrated at Whitehouse, FL where a block of earth 60 ft in diameter and 25 ft deep was lifted. Horizontal fractures were extended from seven injection holes to form the bottom barrier. The block was displaced upward as much as 12 in. by the injection of approximately 2,000 ft^3 of bentonite slurry. Upward displacement was monitored by standard survey techniques during the lifting process. After displacement was completed, a topographic survey was conducted and the quality of the bottom barrier was assessed by core drilling.

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This report is intended to present information on the application of a technology for the control of specific problems caused by uncontrolled waste sites. It is not intended to address every conceivable waste site problem or all possible applications of this technology. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providng an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the U.S. Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes the results of a field experiment to demonstrate Block Displacement as a technique for isolating contaminated soil masses at a hazardous waste site. It will be useful to both design and construction engineers planning site remedial actions, and to action review officials in evaluating the potential of proposals to place a bottom isolation barrier beneath contaminated soil areas. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

The Block Displacement technique has been developed as a remedial action method for isolating large tracks of ground contaminated by hazardous waste. The technique places a low permeability barrier around and under a large block of contaminated earth.

The Block Displacement process is composed of separate bottom barrier and perimeter barrier construction processes. The bottom barrier construction is accomplished by propagating horizontal separations from a series of injection wells. A soil-bentonite slurry is pumped into these wells at low pressure opening the separation and forming a barrier. In the process the ground is displaced upward by an amount corresponding to the thickness of the final barrier placed. The perimeter barrier is constructed by one of various means including slurry wall, jet grouting, or drill notch and blast. The perimeter barrier is constructed prior to the bottom if necessary to induce a favorable in-situ stress state.

The technique was demonstrated at Whitehouse, FL where a block of earth 60 ft in diameter and 25 ft deep was lifted. Horizontal fractures were extended from seven injection holes to form the bottom barrier. The block was displaced upward as much as 12 in. by the injection of approximately 2,000 ft^3 of bentonite slurry. Upward displacement was monitored by standard survey techniques during the lifting process. After displacement was completed, a topographic survey was conducted and the quality of the bottom barrier was assessed by core drilling.

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SECTION 1

INTRODUCTION

1.1 PURPOSE OF THIS WORK

In recent times, the pollution of ground and groundwater due to improper disposal of toxic and hazardous chemicals has become a subject of national awareness and grave concern. The need to control pollution migration and to clean up thousands of hazardous waste sites has lead to the innovation and adaptation of multidisciplinary construction techniques as remedies.

The Block Displacement technique is an innovative adaptation of several diverse construction processes combined to form an innovative remedial option. Hydraulic fracturing (an oil field recovery enhancement technique), jet grouting (a seepage control process), and mud jacking (a foundation settlement corrective technique) have all been combined into this isolation process. The resulting technique is a new method of completely isolating contaminated ground from the surrounding biosphere. The technique is intended as a complementary technology to slurry wall and other perimeter construction processes which produce vertically oriented groundwater seepage barriers. The Block Displacement technique produces a low permeability underlying barrier where naturally occurring strata does not offer such a barrier. As with a slurry wall keyed into a low permeability underlying strata, Block Displacement can be used as a stand-alone technology or as a containment structure to enhance groundwater flushing and in situ treatment techniques.

This report documents a full scale demonstration of the Block Displacement technique conducted in favorable geology adjacent to a national priority waste site. This report documents that effort and discusses the theory and applicational constraints of the process. Design, construction and cost elements associated with the technique are presented. Methods for preconstruction site evaluation and performance monitoring are also suggested.

1.2 PROCESS DESCRIPTION

This section provides a description of the Block Displacement technique, a comparison of the technique to other grouting technologies and a discussion of its compatibility with other construction practices.

1.2.1 Description of the Block Displacement Technique

Block Displacement is a method for vertically lifting a large mass of earth. The technique produces a fixed underground physical barrier around and beneath the earth mass. The barrier is formed by pumping slurry, composed of a soil bentonite and water mixture, into a series of notched injection holes. The resulting barrier completely isolates the earth mass.

The process is illustrated in Figure 1 for isolating a chemical waste site. In-ground pollution is contained by inhibiting groundwater migration through the contaminated zone. The barrier material should be compatible with in situ soil and groundwater chemistry.

A bottom barrier is formed when lenticular separations extending from horizontal notches at the base of injection holes coalesce into a larger separation beneath the ground being isolated as shown in Figure 2.

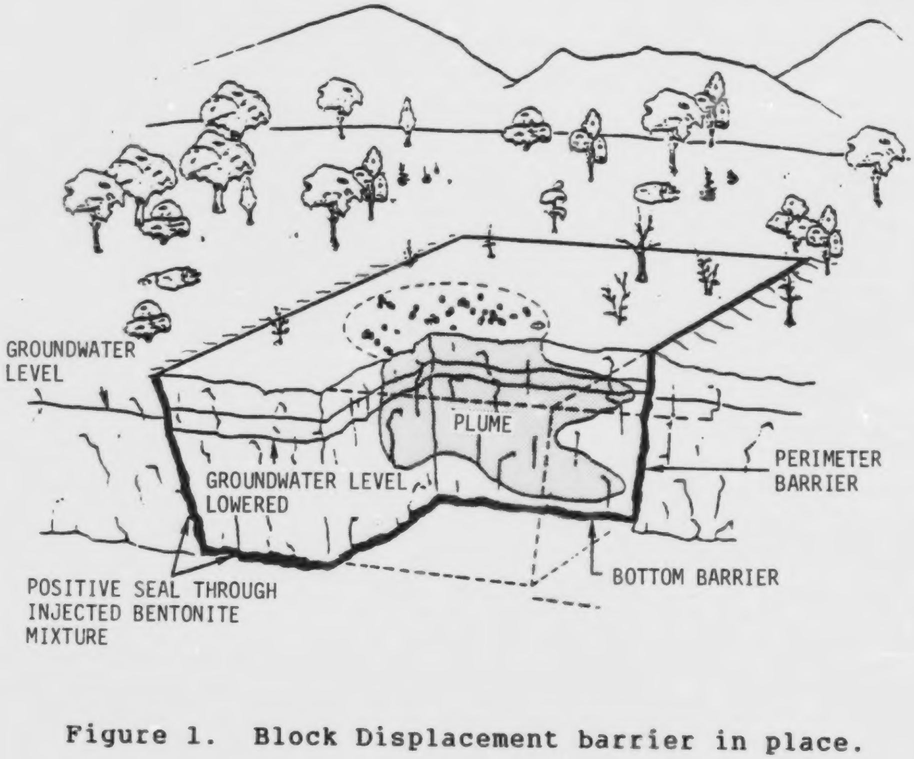
GROUNDWATER LEVEL
PLUME
GROUNDWATER LEVEL LOWERED
PERIMETER BARRIER
BOTTOM BARRIER
POSITIVE SEAL THROUGH INJECTED BENTONITE MIXTURE

Figure 1. Block Displacement barrier in place.

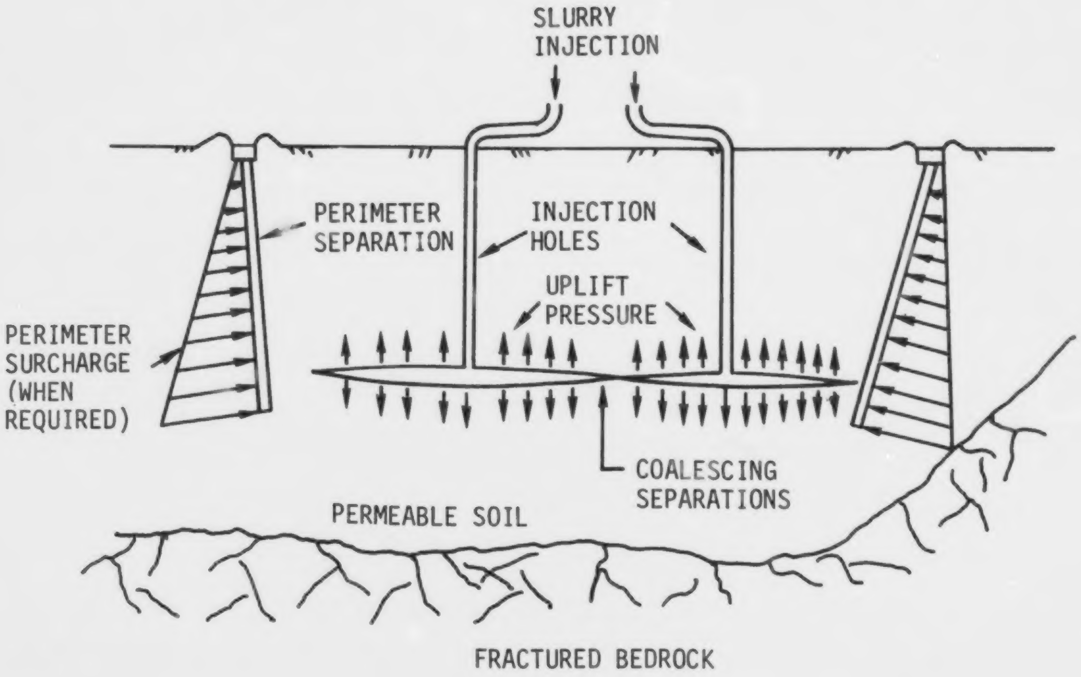
SLURRY INJECTION
PERIMETER SEPARATION
INJECTION HOLES
UPLIFT PRESSURE
PERIMETER SURCHARGE (WHEN REQUIRED)
COALESCING SEPARATIONS
PERMEABLE SOIL
FRACTURED BEDROCK

Figure 2. Creating separation to induce displacement.

Continued pumping of slurry under pressure produces a large uplift force against the bottom of the block and results in vertical displacement proportional to the volume of slurry pumped.

A perimeter barrier is constructed in conjunction with the bottom barrier either prior to, during, or following bottom barrier construction. The perimeter barrier can be constructed by various means including slurry wall, vibrating beam, dynamic fracturing, or jet grouting techniques. If constructed prior to bottom separation, the perimeter barrier can be used to enhance the horizontal stress field for the purpose of maintaining the horizontal orientation of the propagating bottom separations. A perimeter separation would first be constructed and then surcharged to increase the horizontal stress field in the formation (Figure 2). A surcharge is additional pressure transmitted to the fluid slurry in the perimeter separation either by raising the slurry fluid level above ground level or by placing a seal in the perimeter separation and pressurizing the slurry below the seal.

The Block Displacement method can be used to increase the width of an initially thin perimeter barrier such as might be constructed by vibrating beam, dynamic fracturing, or jet grouting techniques. To increase perimeter width by means of the block lift, the thin perimeter must be constructed on a slight angle off vertical prior to a substantial portion of the lift. The slight angle, ϕ, off vertical tapers inward toward the block center. Upward displacement, d, of the block resulting from injection along the bottom barrier will then increase the initial thickness of the perimeter separation, W_o, to the desired barrier thickness, W, according to:

$$W = d \sin \phi + W_o \tag{1}$$

Construction of the bottom barrier proceeds in four phases:

1. Formation of notches at the base of the injection holes
2. Initial bottom separation at the notched holes
3. Propagation of the local separations at each injection point coalescing into a single larger bottom separation
4. Generation of a complete bottom barrier by controlled vertical displacement of the earth mass using low pressure slurry injection into the horizontal separation.

Each of these phases is carried out through control and monitoring of slurry pressure, slurry flow rate, total volume injected, and slurry composition. Deformation and vertical displacement of the isolated soil is also monitored.

The notching operation (Phase 1) requires a high-pressure rotating jet at the base of the injection hole as shown in Figure 3. The jetting slurry is designed to optimize notch erosion, to remove cuttings, and to minimize leak-off into the soil. A mechanical notching tool can be used in lieu of the jet notching tool, but the maximum notch diameter achievable will be reduced. A large notch diameter is desired to reduce fracture initiation pressure and to reduce the tendency for propagating separations to turn upward due to unfavorable in situ stress conditions.

The initiation of bottom separation (Phase 2) requires a slurry pressure, P_o, at the separation defined by:

$$P_o = \rho_r g h + \Delta P \tag{2}$$

where ρ_r = the average earth mass density of the soil overlaying the notching operation

g = the gravitation constant

ΔP = the pressure in excess of the overburden

h = the depth of the bottom separation

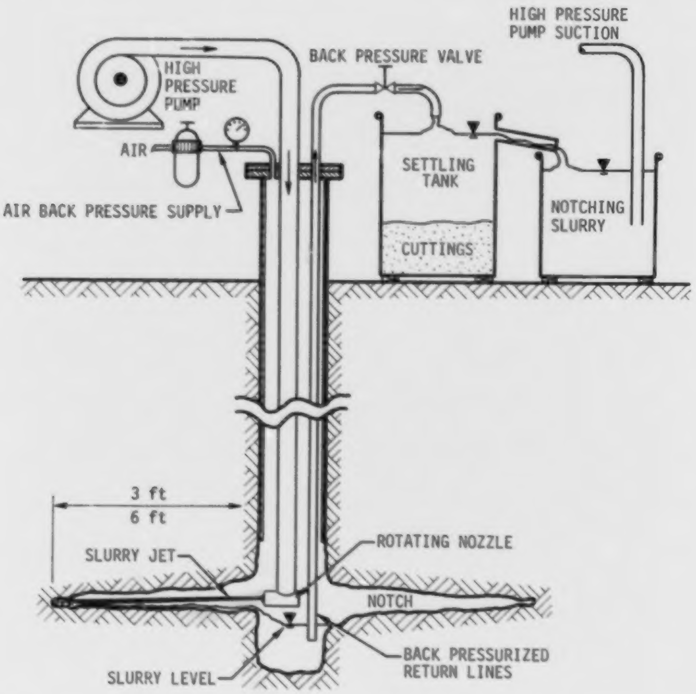
HIGH PRESSURE PUMP SUCTION
HIGH PRESSURE PUMP
BACK PRESSURE VALVE
AIR
AIR BACK PRESSURE SUPPLY
SETTLING TANK
CUTTINGS
NOTCHING SLURRY
3 ft
6 ft
SLURRY JET
ROTATING NOZZLE
NOTCH
SLURRY LEVEL
BACK PRESSURIZED RETURN LINES

Figure 3. Slurry-jet-in-air notching operation.

The pressure in excess of overburden, ΔP, is a function of soil properties, notch diameter, slurry properties and the speed of the operation. The strength of a material being fractured is classically measured by its fracture toughness. In unconsolidated soils, the fracture toughness is negligible. The dominant soil properties are, therefore, the deformation properties including Young's modulus, Poisson's ratio and the coefficient of earth pressure at rest. The initiation pressure can be quantified by treating the notch as two precracked infinite half spaces with pressure applied over the notch length. The pressure required to initiate propagation is the pressure required to open a sufficiently wide gap at the tip of the notch to allow the slurry to flow into the separation. The gap width is dependent on the gel strength of the slurry. The tendency for the slurry to leak off into the soil and form filter cake at the tip of the notch complicates this process and increases the required initiation pressure. This effect can be minimized by using slurry with a low solids content and by minimizing the time available for filter cake to build. A theoretical discussion of the fracture initiation and propagation processes is presented in subsection 4.2 of this report.

Separation coalescence (Phase 3) is brought about by adding slurry volume and by gradually increasing the gel strength and viscosity of the slurry. Slurry pressure required to propagate the horizontal separation will decrease during this phase due to the increased area over which it is acting. The viscosity of the slurry serves to limit flow in one specific direction, thereby avoiding undesirable channeling of slurry material. The higher viscosity increases pressure drop at distances from the injection holes, reducing the pressure available for fracturing. This pressure/distance relationship causes the separations to maintain a generally circular shape in the horizontal plane.

Vertical displacement (Phase 4) utilizes the maximum capacity of the pumping equipment to inject a slurry with high solids content to form the final barrier. When the perimeter barrier separation is constructed prior to displacing the ground, the required injection pressure is dependent on the overburden weight, system geometry, shear resistance in the perimeter and slurry pressure drop across the bottom separation.

The final thickness of the bottom barrier can be controlled to any dimension, from a few inches to several feet. The desired thickness depends on the isolation required by the structure or soil mass being isolated.

1.2.2 Comparison with other Bottom Grouting Techniques

The Block Displacement technique may be viewed as a hybrid, combining traditional vertical seepage barrier technology with innovative bottom grouting technology. It should be noted, however, that Block Displacement involves physical upward displacement of the ground overlying the grouted zone. Traditional bottom grouting techniques either fill existing voids and fractures or replace existing soil with grout without disturbing the overlying ground. The consequence of this distinction is reflected in the methods of process monitoring which are described in subsection 7.4 and indirectly in the cost of implementation.

A comparison of the cost of Block Displacement to the cost of conventional bottom grouting is illustrated qualitatively by comparing these processes on a geometric basis as shown in Figure 4. The reduced drilling associated with Block Displacement and the consequent cost reduction is evident from this figure. Traditional injection grouting utilizes either cement, bentonite or chemical grout to penetrate the formation. The grout is forced into connected macro voids in soil or joints and fractures in rock. The grout effectively seals the soil or rock throughout the zone of penetration. The major drawbacks to pressure grouting are the limited penetration distance and the expense of the chemical grouts required to penetrate the small voids in fine grain soils. Figure 5 illustrates the

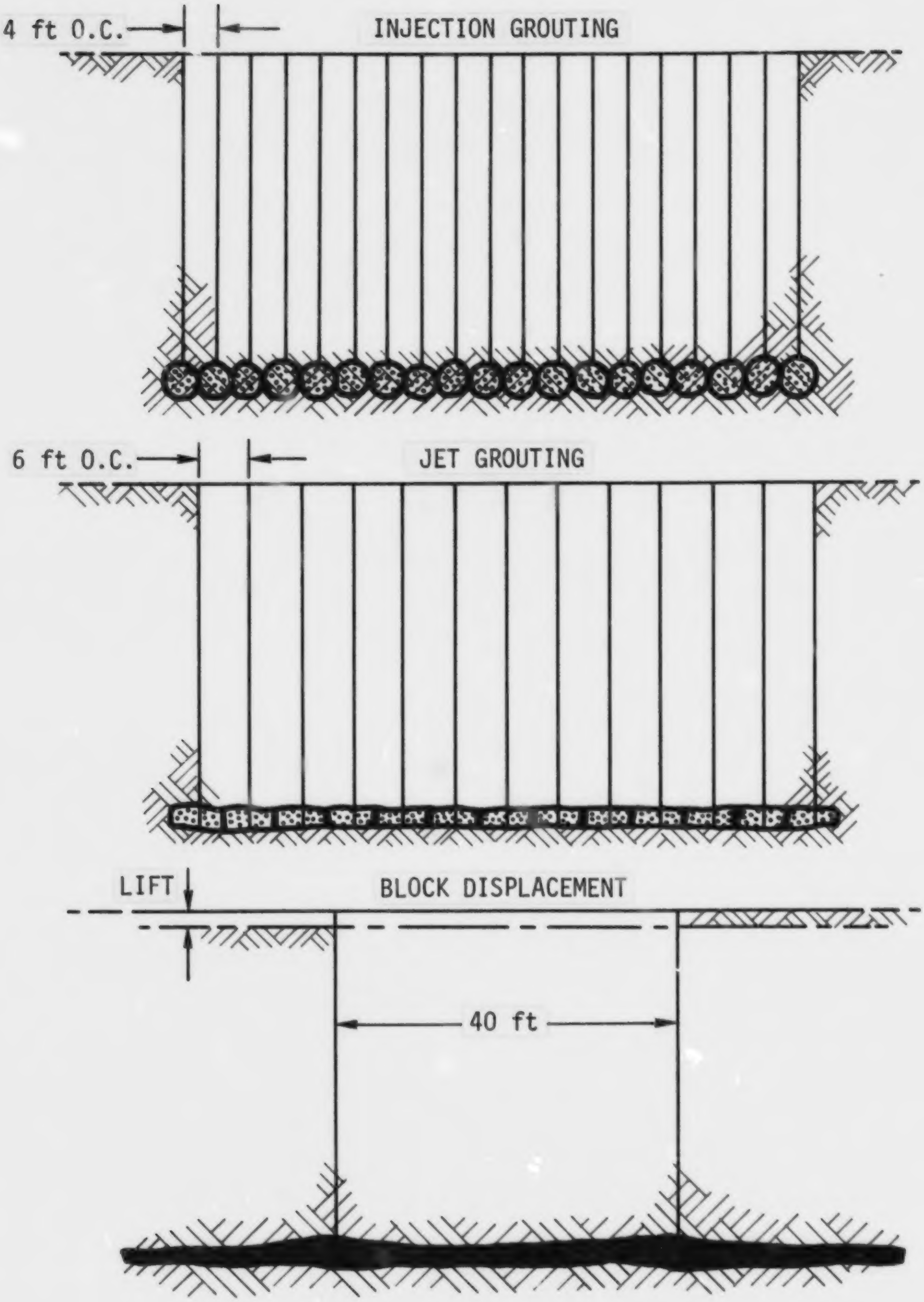
4 ft O.C.
INJECTION GROUTING
6 ft O.C.
JET GROUTING
LIFT
BLOCK DISPLACEMENT
40 ft

Figure 4. Comparison of drilling requirements for alternate bottom barrier construction techniques.

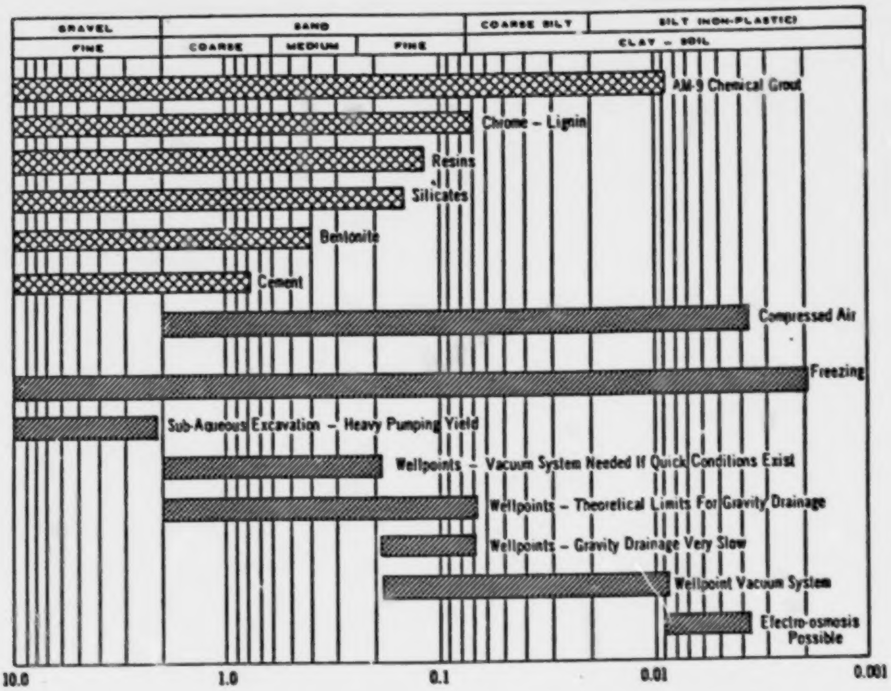

Figure 5. Soil limits for grout injectability.

grain size limitations for various grouts injected into connected soil pores. Typical injection hole spacing for pressure grouting is 2 to 4 ft.*

A grouting technique which is new to the United States, referred to as jet grouting or pancake grouting, has been extensively practiced in Japan and Europe. This technique employs a horizontally oriented, air entrained water jet placed at the bottom of a drill hole. The jet erodes a disc-shaped cavity in the soil several feet in diameter. This inclusion is then backfilled with grout material. By placing these disc-shaped inclusions in a sufficiently close pattern, a continuous grout mat or barrier can be constructed. Typical spacing between inclusions, and hence between drilled holes, is 5 ft. Block Displacement increases the hole spacing of jet grouting by not requiring that jet eroded inclusions (notches) overlap.

Figure 4 illustrates the potential of Block Displacement for increasing the distance between injection points significantly beyond that for either pressure or jet grouting. The potential economic benefits of utilizing Block Displacement as opposed to pressure grouting to form a bottom barrier are derived from increased hole spacing and the use of less expensive grout material. The potential economic benefits over jet grouting are derived from increased hole spacing and a major reduction in the volume of spoil removal required to erode the inclusions. The maximum allowable spacing between injection holes for Block Displacement is geologically and geometrically dependent. The determination of the optimum spacing is a major objective of engineering a site specific design.

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*Throughout this report we have used engineering units that are most familiar to field engineers. Conversions are provided in Appendix F.

SECTION 2

CONCLUSIONS

The Block Displacement demonstration provided three distinct technical conclusions:

- The bottom barrier construction component of the process is viable and has been demonstrated
- The drill, slot and blast perimeter barrier construction technique applied as part of the total isolation process was unsatisfactory and should not be considered for Block Displacement application
- Construction materials, equipment and procedures for implementing the Block Displacement process were evaluated and refined sufficiently to be considered for field application under geologic conditions similar to those at the demonstration site.

The bottom barrier construction technique, which required repeated modification to notching and sealing techniques, ultimately performed quite consistently. Drilling, notching, separation propagation, and block lift were all adequately demonstrated. Surface displacements, core samples and lift volume versus slurry volume correlations all support this conclusion. Subsequent coring data, lift monitoring data and independently derived conclusions from interpretation of ground penetrating radar records (1) indicate at least 80 percent of the underlying area defined by the design perimeter was covered by bottom barrier material.

The drill, slot and blast perimeter separation technique did not produce a sufficiently smooth continuous fracture to allow the perimeter surfaces to fully override each other during the displacement process. Performance of this perimeter separation technique in the more consolidated hardpan is uncertain, as post lift perimeter mapping could not extend down into the hardpan region. Alternate, more direct perimeter construction techniques such as slurry wall or vibrating beam construction would be more appropriate in unconsolidated ground.

Slurry jetting in a compressed air stabilizing medium proved adequate as a bottom notching method in unconsolidated material. Slurry mix, pumping and distributing equipment demonstrated that the slurry designs used can be adequately mixed and placed in the field. Lift monitoring using standard survey equipment was quite adequate for determining performance and as feedback for correcting slurry injection during the lifting operation. Adequate correlation was obtained between slurry injected and ground volume displaced.

SECTION 3

RECOMMENDATIONS

In making our recommendations, FMI refers to the overall objective of the contract under which the work described herein was carried out. That objective was to add the Block Displacement technique to the existing array of available remedial action options, and thus enhance the nation's ability to deal with its uncontrolled hazardous waste problem. This objective was addressed through a test and demonstration program which served to verify the concept and to generate data upon which further development and application of the technique could be based.

To address the overall objective stated above, it is important to take the perspective of the "end user"; i.e., the individual or organization that will specify the use of the method for a specific remedial action. Its use might be specified by a consultant, an architect/engineering firm, a state environmental agency, a regional EPA office, a private waste generator, or a cleanup contractor. From the user's point of view, FMI feels that the following issues will be of greatest concern.

- Continuity between the bottom and perimeter barriers
- Barrier designs and performance
- Monitoring and verification
- Applicability to different geologies.

3.1 COMBINATION OF BOTTOM AND PERIMETER BARRIERS

While the field test at Whitehouse demonstrated the most critical aspect of the method (the bottom seal), a complete barrier was not created due to the inapplicability of the perimeter technique. Certain problems arose, such as tilt and deformation, due to the absence of a dislodged perimeter. In retrospect, a more conventional perimeter technique might have considerably simplified the implementation and improved the final result. We feel that the user community will seek to reference their proposed use of the process to one or more previous demonstrations that were completely successful. Therefore, a demonstration, complete with a conventional perimeter technique, should be conducted.

3.2 CONFIDENCE IN DESIGN AND SUCCESSFUL PERFORMANCE

Being a new technique, the potential performance of Block Displacement in a given situation has a greater degree of uncertainty than more conventional isolation techniques. Our recommendation of the four-step approach was aimed at reducing this uncertainty. A specific procedure recommended for the design phase was a "mini-displacement" test. This procedure would provide feasibility information at relatively low cost and thus minimize the risk to the user. This test should be developed as a future design tool.

3.3 MONITORING AND VERIFICATION TECHNIQUES

The user would like to know whether the process is working while it is being implemented, as well as how it is performing after completion. Monitoring and verification techniques were developed during this program. During the displacement process, we monitored the slurry volume injected versus the volume of lift. Following the displacement process, thin tube sampling was employed to verify barrier continuity. Techniques complementary to these should be developed to provide additional information to the contractor and end user. The most powerful of these would be a drawdown test carried out inside of the block before and after the isolation. This test would evaluate the overall effectiveness of the seal and would represent the best single indicator of the effectiveness of isolation achieved. The absence of the perimeter seal in the demonstration described herein precluded the application and evaluation of this test method. We recommend that this test be developed and employed in future work.

Geophysical methods may also have some applicability in monitoring the overall development of the seal, but only if pre-lift geophysical data are available for comparison. Such techniques would be attractive, but they may require further development.

3.4 APPLICABILITY TO DIFFERENT GEOLOGIES

In considering a site that is not in marine sediments, one must question the applicability of the process to alternate geologies. While there is no shortage of hazardous waste sites located in marine sediments, it will be important, at some point in the near future, to demonstrate the Block Displacement technique in fluvial and/or glacial geologies.

3.5 RECOMMENDED FUTURE WORK

FMI recommends that a second test and demonstration of the Block Displacement process be carried out at a scale roughly similar to that which existed at the Whitehouse site. This demonstration should be configured to address the concerns stated above. Such a test and demonstration could represent a final development step to precede implementation at hazardous waste sites.

The recommended demonstration would be carried out in conjunction with a mechanically excavated perimeter barrier technique, such as a vibrating beam barrier or a slurry trench. The result would demonstrate complete communication between the bottom and perimeter; it would enable the demonstration of controlled lift and uniform seal thickness; and it would allow for the implementation of a drawdown type verification test. Most important, it would demonstrate the complete process.

The proposed demonstration should also be used as a means for developing pilot testing techniques. Using exploration wells or injection wells, several small scale displacement tests could be run as part of the initial site investigation. These mini-displacement tests would verify the displacement process in a site specific geology prior to full scale implementation. These tests would also serve as a major source of design information for the full scale block displacement. The feasibility of obtaining this data and its usefulness in designing the overall Block Displacement application would be evaluated as part of this second demonstration.

A second full scale demonstration should serve as a focal point for developing improved monitoring and verification techniques. The most important of these will be drawdown monitoring of barrier performance. In addition, it would be desirable to employ geophysical techniques before, during, and after the displacement process.

A final consideration for such a test and demonstration is the geology in which it is conducted. To fully address the above stated concerns, tests should be carried out under geologic conditions similar to those in which future real site application is anticipated.

An alternative approach to advancing the state-of-the-art of this technology is to apply the refined process directly to a full scale waste site in geologic conditions similar to those of the Whitehouse demonstration site. To mitigate the risk of real site implementation without further demonstration of the technology, the Block Displacement process should be used in conjunction with a cleanup process such as groundwater flushing. In this way, the barrier need not be perfect as it is merely used as a construction tool to enhance the efficiency of the flushing process. The risk of incomplete isolation is only the risk that a greater quantity of flushing is required.

SECTION 4

BACKGROUND

This section of the report discusses application constraints, process theory and barrier material properties. This information is intended as a reference for the engineer carrying out feasibility or design efforts. A basic format for design and implementation is presented in Section 7.

4.1 CHARACTERISTICS OF APPLICABLE SITES

Not all chemical waste sites are suitable for Block Displacement application. The need for complete physical isolation must first be established. Furthermore, it must be ascertained that adequate isolation cannot be achieved by simpler, less expensive means such as groundwater pumping or slurry wall construction.

A site considered for Block Displacement application should meet all compatibility criteria. For the purpose of discussion, these criteria have been divided into the following groups:

- Geologic compatibility criteria
- Waste compatibility criteria
- Site proximity and size criteria.

An evaluation of the suitability of a specific site for Block Displacement based on the above criteria must consider the intended remedial approach. Block displacement can be employed either for permanent isolation of contaminated ground or as a temporary containment vessel in which to perform additional cleanup activities.

As a permanent stand-alone solution, the barrier must withstand long-term exposure to the waste and waste leachate being contained. Compatibility of the barrier materials and the waste materials is of primary importance in this situation.

As a temporary vessel to contain cleanup activities such as groundwater flushing or in situ treatment, the cost of Block Displacement must be justified by an associated cost savings in the cleanup process. In this case, site geology and size considerations, which impact the cost of Block Displacement, are of primary interest.

Block Displacement may be justified if there appears no alternative for mitigating the serious off-site migration of contaminants. Site proximity impacts this type of "last resort" decision.

4.1.1 Geologic Compatibility

The vast majority of chemical waste sites are located in the transported and deposited soils overlaying bedrock formations. Characteristics of these deposits which impact Block Displacement application are related to the mechanisms of transport and deposition. The five major types of deposits are:

- Alluvial deposits
- Lacustrine deposits
- Marine deposits
- Wind deposits
- Glacial deposits.

Characteristics of each of these deposits are discussed below along with their implications regarding Block Displacement application. These characteristics are summarized in Table 1. Applicability of Block Displacement within bedrock formations is discussed following the discussion of soil deposition.

The most satisfactory characteristics for Block Displacement application are:

- Low topographic relief (flat ground)

- Consistent depth to bedrock, or bedrock sufficiently remote to exclude its influence on propagating separations

- Low bulk density

- A consistent, moderate permeability at the desired bottom barrier depth with lower permeability in overlying and underlying strata

- Well sorted grain size distribution with maximum grain size smaller than cobbles at the intended barrier depth

- High contrast in vertical properties (Block Displacement can take advantage of highly stratified lithology if it is reasonably horizontal)

- Low contrast or a high degree of continuity in the lateral direction.

TABLE 1. MAJOR SURFICIAL DEPOSITS OF THE CONTINENTAL UNITED STATES

Characteristic	Alluvial deposits	Lacustrine deposits	Marine deposits	Wind deposits	Glacial deposits
Topography	Alluvial fans - Undulating Valley fills - low	Low	Low	Undulating	Complex
Depth to bedrock	Highly variable	Consistent	Consistent	Variable	Highly variable
Bulk density	Variable	Low/ moderate	Low/ moderate		Highly variable
Permeability	Silts-low Sands-high	Silts-low Sands-high	Moderate	Low horizontal High vertical uniform	Tills-low glacial-fluvial-high
Grain size distribution	Uniform within beds; Extreme variation between beds	Uniform within bed	Well sorted		Extreme rock powder to boulders
Continuity lateral	Often discontinuous	Locally consistent	Consistent	Consistent	Location dependent
Vertical	Stratified	Stratified	Stratified	Consistent	Can be complex

Sites with the following characteristics at the intended depth of the bottom barrier construction should be avoided:

- Solution channels (as found in Karst limestone bedrock)
- Excessive connected open joints
- Void bound composite soil structures with large connected voids
- Intrusive dikes, shear zones and major faults

- Steeply dipping or highly contorted bedding
- Uniform graded soil with dominant grain size exceeding fine grained gravel
- Well graded soil with maximum grain size exceeding cobbles.

These characteristics should be avoided as they will either lead to excess slurry loss during injection, or will cause misdirection of the propagating separation resulting in a lack of continuity in the barrier placed.

In addition to avoiding sites with these characteristics, the contrast in soil strength, permeability and Young's modulus due to stratification, as well as anisotropy in strength, permeability and in situ stresses, must be taken into account in deriving permissible injection hole spacing.

The discussions which follow describe the impact of characteristics of a particular deposit on Block Displacement application. These impacts have been surmised from theoretical studies, laboratory testing and a single, full scale field demonstration conducted in marine sediments as described in Section 5. These effects are, therefore, the author's hypothesis based on engineering judgement and have not been verified by application experience.

Alluvial (River) Deposits--

Alluvial deposits are characterized by two formations: alluvial fans and valley fills.

Alluvial fans are less desirable for Block Displacement due to their characteristic undulating surface underlain by highly erratic depositions of sand and gravel. Block Displacement operations of limited size may be considered within these deposits, but a thorough geologic investigation must be carried out to define the deposit geometry. Surface grading will likely be required to provide a level surface and a block of uniform thickness. Blocks with significant variations in thickness are likely to be difficult to displace uniformly.

Valley fills are generally well suited to Block Displacement due to relatively broad reaching horizontal strata. Flood plain regions are particularly well suited with sediments similar to lake deposits. Caution must be taken that the proposed displacement region is not intersected by river deposits such as braiding or small scale oxbows which can introduce discontinuities in otherwise consistent horizontal strata. A large oxbow which encompasses the entire site may have sufficient continuity within its boundries to apply Block Displacement.

Lacustrine (Lake) Deposits--

Lacustrine deposits are generally well suited to Block Displacement application. Where streams enter a lake, delta deposits are formed. These deposits will be composed of layers of uniform sand usually with a dip in the bedding angle. The soil layers, while uniform within a layer, alternate between coarse and fine grained sand. The bedding angle must be taken into account if properties of alternate beds have a high contrast.

Peat bogs or swamps often overlay lake deposits. These deposits are structurally weak and compressible; therefore, stratification contrast should be exploited where possible when applying Block Displacement. The viscosity of the initial fracture fluid should be kept low to minimize strain on these formations. Varved clays which are common to lake deposits are ideal media for propagating horizontal fractures or separations.

Marine Deposits--

Offshore marine deposits are generally very continuous, horizontally stratified deposits, and are, therefore, ideal for Block Displacement application. Caution must be taken, however, to avoid cavernous limestone formations which often underlay unconsolidated marine deposits. Uniform marl formations, however, are generally acceptable.

Shore deposits are more complex than offshore deposits. Typically composed of sand dunes of coarse grained sand, these deposits are often discontinuous. Bedding should not be relied upon as a means of increasing injection hole spacing, since these strata may pinch out as lenses. Typically, these deposits exhibit uniform grain size at a single location, but vary considerably in grain size throughout the deposit. Exceptions are shore lagoons which form in a fashion similar to lake deposits, except that thick sand lenses often bound these more favorably stratified deposits.

Wind Blown Deposits--

Wind blown deposits such as those found in the desert are usually composed of uniform round sand. There is little contrast in these deposits, making them highly predictable regarding Block Displacement. Due to a lack of contrast between strata, these deposits many be treated as a homogenous material.

Fine grained, wind blown deposits referred to as loess are common to the Midwest. These deposits, composed of uniform silts, are acceptable if the deposits were formed under water. Otherwise, these deposits are generally vertically connected by root holes causing high vertical permeability. These vertical connections are undesirable for Block Displacement application, since these can lead to vertical migration of injected slurry and weaknesses contributing to vertical cleavage or shear failures.

Glacial Deposits--

The structure of glacially deposited soils is generally complex. The deposits formed by soil laden ice usually have an extreme range in grain size, from boulders to rock flour. The complexity of structure combined with the presence of boulders makes glacial deposits generally poorly suited to Block Displacement application. However where melt water filled depressions left by retreating ice, the deposits are similar to lacustrine deposits and may be suitable for Block Displacement. These lake deposits are often extensive and may include varved clays which should be suitable for Block Displacement application.

Bedrock Formations--

Evaluation of Block Displacement applicability in bedrock is complicated by the degree of rock weathering, associated with its proximity to the ground surface. Weathering weakens the rock, often creating vertically oriented joints. Open joints create paths for vertical migration of slurry. Closed joints or joints filled with fine grain material would inhibit this migration.

In sedimentary rocks such as shale, horizontal weaknesses due to bedding or stratification can be exploited for aligning propagating separations produced by injected slurry. These weaknesses will be much more dominant than in stratified soils, since the rock between bedding or cleavage planes can have significant shear strength. Among the sedimentary rocks, however, limestone formations should be avoided. Karst limestone deposits contain solution channels which, if intersected by a propagating separation, would produce an immediate avenue for slurry loss.

Karst formations as well as dikes, shear zones, and faults should be avoided as these can lead to slurry loss and the formation of a discontinuous underlying barrier. Weathered igneous rock formations are not well suited to Block Displacement application.

4.1.2 Waste Compatibility

The slurry materials used for Block Displacement are similar to those used for soil/bentonite slurry wall construction. The compatibility criteria for slurry wall construction apply in a similar fashion to Block Displacement. The potential for using slurry materials other than soil/bentonite (such as asphalt emulsions) exists, but will not be discussed here as their use has not been demonstrated.

Soil/bentonite slurries may be exposed to on-site contaminants in the waste either as a result of construction procedures or as a result of gradual migration of groundwater within the contained zone following construction. Exposure to contaminants can result in flocculation, inhibiting hydration of the bentonite. In the extreme case, the bentonite and soil will settle out of suspension, destroying the fluid and sealing properties of the slurry. If this occurs during barrier construction, the slurry injection process would have to be terminated and could not be re-initiated until a satisfactory "buffered" slurry was devised. The most common cause of flocculation is reduction in swelling capacity due to ion exchange. The monovalent sodium ions associated with sodium montmorillonite (bentonite) are readily replaceable by multivalent cations such as calcium. This replacement results in decreased swelling, leading to flocculation in the extreme case. Buffers can be added to the bentonite slurry to impede this exchange.

Following successful construction, the barrier may be vulnerable to longer term deterioration from exposure to various organic and inorganic compounds. Table 2 indicates the effect of various chemicals on both pure bentonite filter cake and on a soil/bentonite mix containing 30 to 40 percent fines.

As indicated by these data, extreme pH (greater than 11 or less than 1), as well as alcohol, has a strong effect on barrier permeability.

Bentonite suppliers claim that certain brands of bentonite, containing polymers and other proprietary additives, can mitigate the effects of exposure to waste leachate. Table 3, which compares the permeabilities of four brands of bentonite to selected leachates, indicates little difference between these particular brands. However, the list of contaminants and the list of modified bentonites is extensive.

Until long term compatibility data is documented, site specific testing will be required for correlating resistance of these bentonites to the various waste leachates through meaningful ranges of concentration. Candidate slurry designs should be exposed to leachate sampled from the specific site for which Block Displacement is proposed. This exposure can best be carried out using an accelerated permeability test. Soil and barrier slurry should be placed in a column and leachate permeated through the material at an accelerated rate. Practical time constraints require accelerated testing by increasing the pressure drop across the column above that anticipated at the site. This will allow a sufficient number of pore volume equivalents of leachate to pass through the barrier material in a reasonable length of time. There is not, at present, a universally accepted procedure, but the trend appears to be toward applying sufficient pressure to pass four or more pore volume equivalents through the barrier in the time allotted for testing. The test period is generally several months. There is controversy regarding the need for triaxial conditions in these tests and regarding a biasing effect resulting from testing at a pressure gradient greater than anticipated at the site.

TABLE 2. SOIL BENTONITE PERMEABILITY INCREASE DUE TO LEACHING WITH VARIOUS POLLUTANTS (2)

Pollutant	Filter cake	SB backfill (silty or clayey sand) 30 to 40% fines
CA++ or Mg++ at 1,000 ppm	N	N
CA++ or Mg++ at 10,000 ppm	M	M
NH_4NO_3 at 10,000 ppm	M	M
HCL (1%)	N	N
H_2SO_4 (1%)	M	N
HCL (5%)	M/H*	M/H*
MaOH (1%)	M	M
CaOH (1%)	M	M
NaOH (5%)	M	M/H*
Sea water	N/M	N/M
Brine (SG = 1.2)	M	M
Acid mine drainage ($FeSO_4$; pH 3)	N	N
Lignin (in CA++ solution)	N	N
Alcohol	H (failure)	M/H

*Significant dissolution likely.

Note: N = No significant effect, permeability increase by about a factor of 2 or less at steady state.
M = Moderate effect, permeability increase by factor of 2 to 5 at steady state.
H = Permeability increase by factor of 5 to 10.

TABLE 3. INCREASE IN THE PERMEABILITY OF FOUR BRANDS OF BENTONITE CAUSED BY LEACHING WITH VARIOUS POLLUTANTS (2)

	Final permeability/initial permeability			
Permeant	Slurry Ben 125	National Premium Brand	Saline Seal 100	Dowell M179
Lignin in Ca++ solution	1.9	1.5	2.5	1.4
NaCl based salt solution (conductivity 170,000)	2.7	1.8	2.7	N/A
Ammonium nitrate (10,000 ppm)	1.8	N/A	2.8	N/A
Acid mine drainage (pH 3)	N/A	1.5	1.3	N/A
Calcium and magnesium salt solution (10,000 ppm)	2.9	3.2	3.2	N/A

N/A: Data not available.

4.1.3 Site Proximity and Size

Site size and location must also be considered when assessing Block Displacement viability. Adequate access must be available to bring drill rigs and trenching equipment on site. Buried materials must be capable of supporting the bearing load of the drill rig. Foundations of nearby structures, utility poles and buried utilities all may be affected by displacing the ground. Topography of the block is of paramount importance. If the ground is not level, steps must be taken by leveling, shifting near surface material, or by perimeter surcharge to assure balanced lateral and lift forces to avoid block tilt during the lift operation.

The upward movement of isolated ground associated with Block Displacement imposes constraints on structures and conduits which intersect the displaced site. The magnitude of displacement necessary to produce an effective barrier may be one or more feet. This amount of vertical offset at the perimeter of a site could damage buried conduits crossing the perimeter. Adjacent foundations might experience settlement problems as well.

The size and shape of a site requiring isolation will impact the method of Block Displacement application. Elongated sites such as valley fills with extended contaminant plumes would require a progressive application of the process. The displacement would be initiated at one end of the site and progress across the site. Care must be taken to maintain a gradual distortion of the overlaying soil. The maximum permissible distortion of the soil would be a function of soil properties and barrier depth.

The desired depth of the bottom barrier will have direct impact on injection hole spacing. The available manpower and equipment will limit the number of injection holes to which slurry can be simultaneously pumped. If the required number of injection holes exceeds this number, either progressive displacement as described above or sequential lift of multiple cells would be required.

4.2 THEORETICAL BACKGROUND

The theoretical basis for predicting the response of a geologic medium to the application of Block Displacement is adapted from studies of hydraulic fracture. There are five principal types of analysis that can be employed to quantify design parameters for a specific geologic site:

- Analysis to determine slurry injector pressure requirements and limitations
- Analysis to determine slurry volume and flow requirements
- Analysis to determine direction of propagation of fractures (separations)
- Analysis to determine perimeter barrier sealing requirements
- Analysis to determine lift control requirements.

Each of these analyses will be described in the subsections that follow. These analyses are useful for determining slurry design and injection hole spacing, specifying perimeter and bottom barrier interactive requirements, and establishing notching and pumping operational procedures.

Safety factors and permissible deviation from uniformity of bottom barrier geometry are not stipulated, as these are decisions which must be made by the designer/engineer.

Slurry Injection Pressure

The construction of a bottom barrier using Block Displacement requires injection of slurry to initiate, propogate and coalesce fractures or separations as described in subsection 1.2 of this report. The downhole slurry pressure required to initiate the separation is dependent on notch size. A large notch size is desired to minimize this initiation pressure. The initiation pressure, P_o, can be calculated from:

$$P_o = \rho_r gh + \Delta P \qquad (2)$$

where ρ_r = the average earth mass density (unit weight of soil)

g = the gravitational constant

h = the depth of the bottom separation

ΔP = the pressure in excess of the overburden

The initiation pressure, Po, is the pressure at the notch located at the bottom of the injection well. If injection pressure is measured at the well head, the hydraulic head of the slurry inside the well casing must be added to the measured value.

There is considerable uncertainty regarding the pressure in excess of overburden required to initiate failure propagation. There are empirical data from both laboratory and field trials (3) which indicate that substantial excess pressure is required. In cohesionless material, analysis of distortion of an infinite half space subjected to a uniform pressure along the notch can be used to establish a correlation between injection pressure, p, and fracture opening width, Lw, as shown in Figure 6.

When the perimeter barrier separation is constructed prior to displacing the block, the required injection pressure, P_o, is dependent on the block weight, block geometry, shear resistance in the perimeter and slurry pressure drop across the bottom separation. The relationship is derived as follows:

$$P_o = P_1 + \Delta P_B \qquad (3)$$

where P_1 = the pressure in the bottom separation at its intersection with the perimeter separation

ΔP_B = the pressure drop across the bottom separation due to flow resistance in the slurry

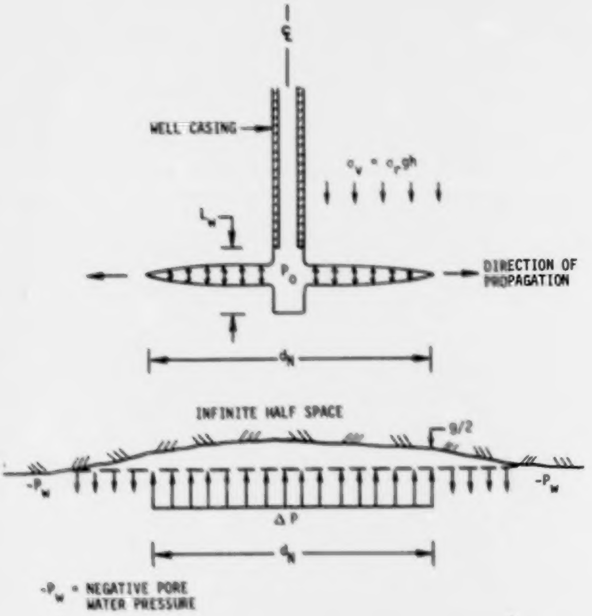

℄
WELL CASING
σ_v = ρ_r gh
L_w
P_o
DIRECTION OF PROPAGATION
d_N
INFINITE HALF SPACE
g/2
-P_w
-P_w
ΔP
d_N
-P_w = NEGATIVE PORE WATER PRESSURE

Figure 6. Influences on initiation pressure, P_o.

The average pressure pushing upward on the bottom of the block, P_B, is a function of P_1 and ΔP_B. By geometry

$$P_B = P_1 + 1/3\ \Delta P_B \tag{4}$$

The balance of vertical forces on the block yields the relationship

$$P_B A_B = \rho_r g h A_B + t A_p \tag{5}$$

where A_B = the area of bottom separation

t = the shear strength of the perimeter separation

A_p = the area of the perimeter separation

Combining Equations 3, 4 and 5 yields

$$P_o = 2/3\ \Delta P_B + \rho_r g h + (t A_p / A_B) \tag{6}$$

or

$$\Delta P = 2/3\ \Delta P_B + t(A_p / A_B) \tag{7}$$

The width required to allow slurry to flow forward into the open fracture also depends on slurry properties such as gel strength and viscosity. Work carried out to date indicates that a fracture opening about 3/8 in. wide is required when injecting a 4 to 8 percent by weight bentonite in water slurry.

A second and perhaps more important analysis is that of establishing upper limits on a permissible injection pressure based on classical anchor pull shear failure analysis (4). The injection pressure applied across the upper surface of the notch can be equated to an anchor pulled vertically upward. The permissible injection pressure should be limited to assure that this type of soil failure does not occur.

Slurry Volume and Flow Requirements

Both laboratory and field tests have demonstrated high correlation between the volume of slurry injected and the measured vertical lift of the ground displaced. Following an initial period of slurry fluid leak off, filter cake builds on the bottom separation surfaces and subsequent injected slurry meets a barrier of thickness, t, equal to the volume injected, V, divided by the area, H, over which displacement occurs, $t = V/A$. If displacement is carried out prior to constructing a perimeter barrier, this thickness, t, pinches off at the bottom barrier edges thus introducing error into the above calculation. However, this pinch off zone is limited in extent to roughly the spacing between two adjacent injection wells. A more precise calculation can be made by assuming the fracture pinches out linearly over this distance. The volume/displacement equation is useful for specifying equipment, injection rates and lift monitoring procedures. Estimates of total quantity of slurry material required must consider both the initial leak off and the subsequent injected volume as defined above.

Direction of Fracture Propagation

The theoretical basis for predicting the fracture propagation process is founded in previous work applied to hydraulic fracture for oil-field applications. These models have been used to predict pumping pressures and flows, as well as fracture orientation for enhanced oil recovery (5). The interaction of multiple horizontally oriented fractures has been discussed by several investigators (6). A rigorous mathematical model has been developed (7) for predicting both fluid slurry properties and fracture propagation geometry for single and multiple interaction fractures. This model employs a surface integral approach, utilizing dislocation theory to predict fracture behavior. Parametric inputs include slurry properties such as viscosity and pumping rate, and geologic properties including modulus of elasticity, Poissons ratio, permeability and in situ stresses.

A computer program employing the Gauss-Chebyshev integration formula can be used to solve the surface integral equations. For the case of a single, initially horizontal fracture, a variation in K_o (where $K_o = \sigma_H/\sigma_V$ and is known as the coefficient of earth pressure at rest) between 0.6 and 0.8 does not predict significant changes in the direction of propagation from the horizontal. This range of K_o is reflective of conditions found in unconsolidated near surface soils.

However, it has been shown that in the presence of a free surface, a fracture paralleling that surface will turn toward the surface, then turn back away from the surface. As the fracture continues to propagate, it approaches the surface asymptotically. Data generated using the Gauss-Chebyshev integration formula for a fracture paralleling a free surface in a uniform stress field is shown in Figure 7 (8). Once the free surface influence has caused the fracture to turn up from its initially horizontal orientation, the influence of the biaxial stress field ($K_o < 1.0$) may cause the fracture to rise at a steeper gradient. This behavior can be tested in the laboratory or in the field by conducting a mini displacement test as illustrated in Figure 8.

Analysis of this combined effort has not been carried out as part of this study. However, laboratory data (9) have shown an extremely steep initial rise in the fracture followed by a rather abrupt return to the horizontal orientation.

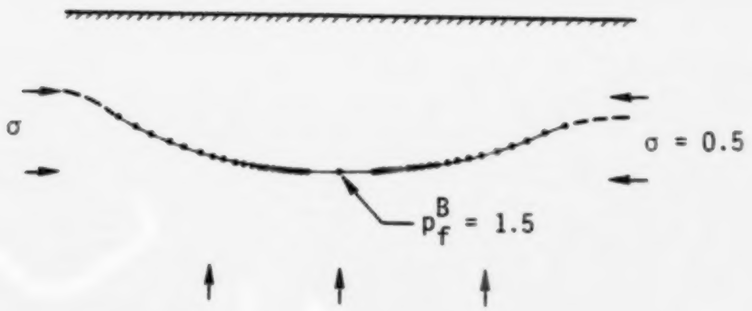


Figure 7. Fracture growth near a free surface.

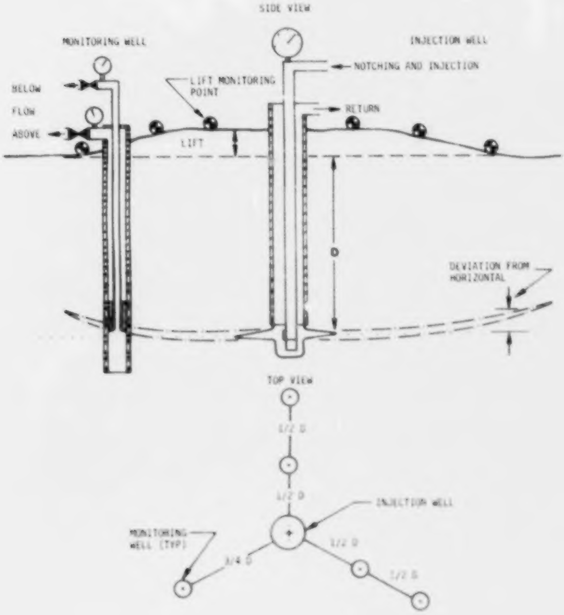

SIDE VIEW
MONITORING WELL
INJECTION WELL
NOTCHING AND INJECTION
BELOW
FLOW
ABOVE
LIFT MONITORING POINT
RETURN
LIFT
D
DEVIATION FROM HORIZONTAL
TOP VIEW
1/2 D
1/2 D
INJECTION WELL
MONITORING WELL (TYP)
3/4 D
1/2 D
1/2 D

Figure 8. Mini displacement test.

Vertical offset in adjacent horizontal fractures resulted in the fracture interaction predicted by Huck (10). The two approaching fractures passed, then turned toward each other as shown in Figure 9.

The author of this report suggests that pore water at the fracture tip significantly influences the fracture propagation process. Behavior observed during laboratory testing has indicated that solution leaking from the slurry propagating the fracture does, in fact, play a major role in the process.

During the fracture propagation portion of the field demonstration, regular pressure fluctuation was observed in the pressure of the slurry being injected. The pressure rose several psi then dropped abruptly. This pressure fluctuation was repeated on a steady basis leading to two refined hypotheses regarding the propagation process.

The first hypothesis is that the slurry pressure builds until it exceeds the gel strength of filter cake which has built up at the fracture tip. Once the gel strength is exceeded, the filter cake barrier is breached and the slurry flows forward into the fracture which has already extended ahead of the barrier. This portion of the fracture, being void of pore fluid, provides volume for the fluid, allowing pressure

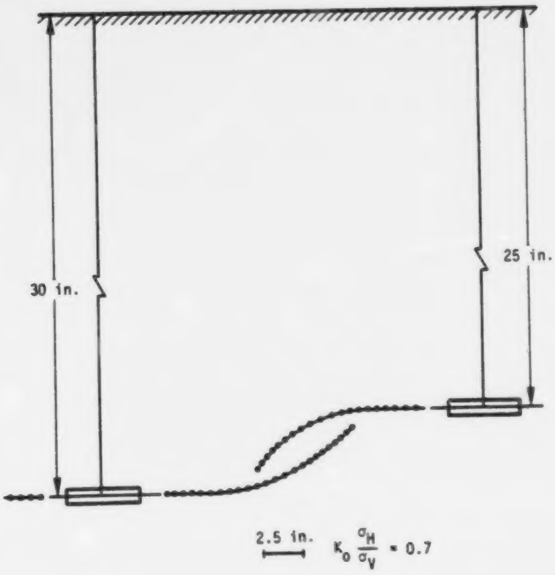


Figure 9. Interaction of offset approaching fractures.

relief and associated relaxation in ground distortion (reduction in fracture width).

The second hypothesis is that the leak-off solution contained clay particles which migrated ahead of the fracture, altering the local stress field and generating a cohesion in the previously cohesionless soil. This cohesion and correspondingly increased fracture toughness of the soil would explain the surging pressure as a reflection of classic unstable fracture growth followed by growth arrest.

One proposed procedure would use high-spirt (high leak-off) slurry early in the process to encourage fracture propagation and then use reduced spirt (low leak-off) slurry to displace the ground once the fracture propagation process is completed. The high spirt slurry has a low solids content (4 percent bentonite) and the low spirt slurry a high solids content (8 percent bentonite). The approach proved effective in generating horizontal fractures and subsequently controlling the displacement process in laboratory tests. The theoretical model presently used to predict the direction of fracture propagation does not, however, take this leak-off property into account. Further theoretical work would be necessary to generate a proper understanding of the observed effect.

Lift Control Requirements

Lift is controlled by pressure gradients in the slurry associated with slurry gel strength and viscosity. This pressure gradient across the bottom is dependent on slurry properties as well as the width of the separation as described in the following subsection.

4.3 SLURRY PROPERTIES

The mechanics of Block Displacement depend on certain properties of slurry compositions used. Bentonite clay-based slurries are similar to drilling muds except that the soil bentonite slurry finally injected to form a seal has a higher solids content than is practical for drilling mud. The slurry properties most significant to the process are density, gel strength, and permeability of filter cake.

Density determines the degree to which hydrostatic head of the slurry can support the weight of the ground being displaced. If the perimeter separation is constructed prior to displacement, perimeter slurry density is of major importance and should have a specific gravity close to 2.0. This high density in the perimeter slurry minimizes the portion of bottom slurry displacement pressure which must be resisted by means other than hydrostatic head.

Gel strength is a measure of the shear strength of the slurry and determines the threshold resistance to flow. The gel strength (t) of the perimeter separation slurry is the measure of shear resistance used in Equation 5 (subsection 4.2). The gel strength of the bottom separation slurry is used to calculate the pressure drop ΔP_B in Equation 3 (subsection 4.2). This threshold flow resistance also provides a mechanism for supporting the unbuoyed weight of the block. The threshold flow resistance for a gelled fluid in a slot is given by:

$$\Delta P_f = 2tl/w \qquad (8)$$

where ΔP_f is the pressure drop along a slot of length l, and width, w, and t is the gel strength of the fluid. When the perimeter separation is constructed prior to displacement, the mean pressure at the underside of the block being displaced, ΔP_B, can be significantly increased above hydrostatic column pressure of the perimeter separation slurry because of the threshold flow resistance of gelled slurry filling the narrow flow passages. Both the flow resistance in the bottom separation and the resistance to flow up the perimeter separation contribute to supporting the unbuoyed weight and perimeter shear resistance of the block. The gel strength of the initially injected slurry is kept low to minimize the initiation pressure. As the separations enlarge and coalesce forming a single bottom separation the gel strength is increased to enhance the uplift force.

The gel strength of the perimeter separation slurry is kept high as its contribution to support of the unbuoyed weight of the block far outstrips its contribution to perimeter shear resistance to displacement.

The benefit to displacement force from high gel strength in the perimeter slurry can be seen by calculating the change in uplift force, ΔF, as a function of gel strength, t, for these two effects combined.

Based on Equation 8

$$\Delta P_1 = 2\Delta t h/w \qquad (9)$$

where the slot length l is replaced by the depth of the perimeter separation, and ΔP_1 is the change in permissible slurry pressure at the intersection of bottom and perimeter separations due to a change in slurry gel strength, Δt.

$$\Delta F = \Delta P_1 A_B - \Delta t A_p \qquad (10)$$

where the first term on the right is the increased uplift force due to the increased pressure and the second term is the increased uplift resistance due to shear. Combining Equations 9 and 10

$$\Delta F = (2\Delta t/w)hA_B - \Delta t A_p \qquad (11)$$

For a circular block of diameter D

$$(A_B = \pi D^2/4 \text{ and } A_p = \pi D h)$$

$$\Delta F = \pi \Delta t h(D/2w - 1) \qquad (12)$$

By Equation 12, it is readily apparent that increased gel strength increases the potential uplift force as long as block diameter is twice the width of the separation. The limiting factor for perimeter separation gel strength is in fact its value relative to the shear strength of the surrounding soil. Part of the purpose of the perimeter separation is to ensure that shear occurs through the perimeter slurry and not through the soil.

The gel strengths of fluids used in Block Displacement range from less than 5 Pa for the low concentration slurry used to initiate and extend the bottom separation fractures, to 40 to 150 Pa for soil bentonite slurry injected into the underside of the block for a major part of the displacement. If needed, substantially higher gel strength slurry ranging to over

1000 Pa may be injected directly into the perimeter separation to help contain block displacement pressure.

All of the slurry compositions used in Block Displacement form very low permeability filter cake. The function of the filter cake is very similar to the function of mud cake in rotary drilling. The cake limits infiltration, while slurry pressure applied to the cake stabilizes the block despite its low intrinsic strength. The low solids concentration slurry used to initiate the bottom separations forms cake very slowly and the cake is soft. This quantity is important to prevent the initially narrow separations from plugging or "healing" with time during early stages of their propagation. The filter cake has a permeability of approximately 10^{-8} cm/sec.

The high concentration soil bentonite slurry, which forms the main mass of thick sealing layer surrounding the displaced block, forms cake much more rapidly because of the small water loss needed to consolidate this slurry from a liquid to a solid. The cake is a plastic solid having fairly high shear strength. The permeability of the cake is roughly 2×10^{-8} cm/sec.

The permeability of a bentonite slurry may be changed adversely by certain cations that may migrate into the barrier over a period of years. Calcium ion is especially detrimental. Design of the barrier should take into account the likelihood of a permeability increase due to the local chemical environment.

Table 4 summarizes the properties of the various slurries used for Block Displacement.

TABLE 4. SLURRY CHARACTERISTICS FOR THE BLOCK DISPLACEMENT METHOD

Function	Density (sp gr)	Gel strength (Pa)	Permeability when consolidated (cm/sec)	Comments
A. Bottom barrier construction				
i) Notching	1.1-1.3	10-20	Based on permissible leak off and soil characteristics	Must match notching tool jet design.
ii) Initiating bottom separation	1.1-1.3	10	Based on permissible leak off and soil characteristics	Low viscosity slurry desired.
iii) Propagation and coalescence	2.0-3.0	20-50	Based on permissible leak off and soil characteristics	
iv) Lift and final barrier	1.8-1.9	50-100	10^{-7}-10^{-8}	High viscosity but pumpable.
B. Perimeter barrier construction				
i) Stabilization	1.5-2.5	20	Based on permissible leak off and soil properites	Indicated values for medium grain sand-varies according to soil properties.
ii) Surcharge (when perimeter is placed prior to lift)	1.9-2.0	200	Based on permissible leak off and soil properties	Maximum density desired, flow requirements minimal.
iii) Final barrier	1.8-1.9	50-100	10^{-7}-10^{-8}	Total barrier permeability and thickness should match the effectiveness of the bottom barrier.

SECTION 5

DESCRIPTION OF FIELD DEMONSTRATION

The demonstration of Block Displacement involved selecting a suitable site, conducting field operations to construct a barrier at that site, and verifying the success of the barrier construction. Figure 10 shows the overall chronology of the Block Displacement field demonstration.

The proposed demonstration was to use a drill, slot and blast technique to generate a perimeter fracture. This technique employs explosives placed in close spaced, parallel holes to produce sheet fractures connecting the holes. The bottom barrier would then be constructed as described in subsection 1.2. The perimeter fracture was intended to form a continuous separation in the shape of an inverted truncated cone. The conical shaped fracture would, therefore, taper inward slightly from vertical as it extended into the ground. This taper would allow the fracture to widen as the block of ground within the perimeter was displaced upward. A taper angle of 14 degrees was selected to assure that asperities in the fracture surface would not interlock during displacement and to produce a sufficiently thick perimeter barrier. Previous work with perimeter barriers including vibrating beam and slurry wall construction had indicated that a 3-in. soil-bentonite barrier would yield adequate seepage control to permit a draw down test to be conducted for verifying the Block Displacement process. The corresponding vertical displacement required would be 12 in. It was believed that this amount of displacement would not only produce the 3-in. thick perimeter, but would insure a continuous bottom barrier. Furthermore, this magnitude of physical displacement would be easily observable at the surface.

5.1 SITE SELECTION

The demonstration site was to be selected from the EPA list of the first 114 top priority superfund sites, released Friday, October 23, 1981. The list contained a brief description of the sites and only sketchy geologic information.

The criteria for site selection was based on immediate accessibility, as well as geologic conditions. The following access and geological criteria were used to reduce the list of 114 sites to less than 20 candidates.

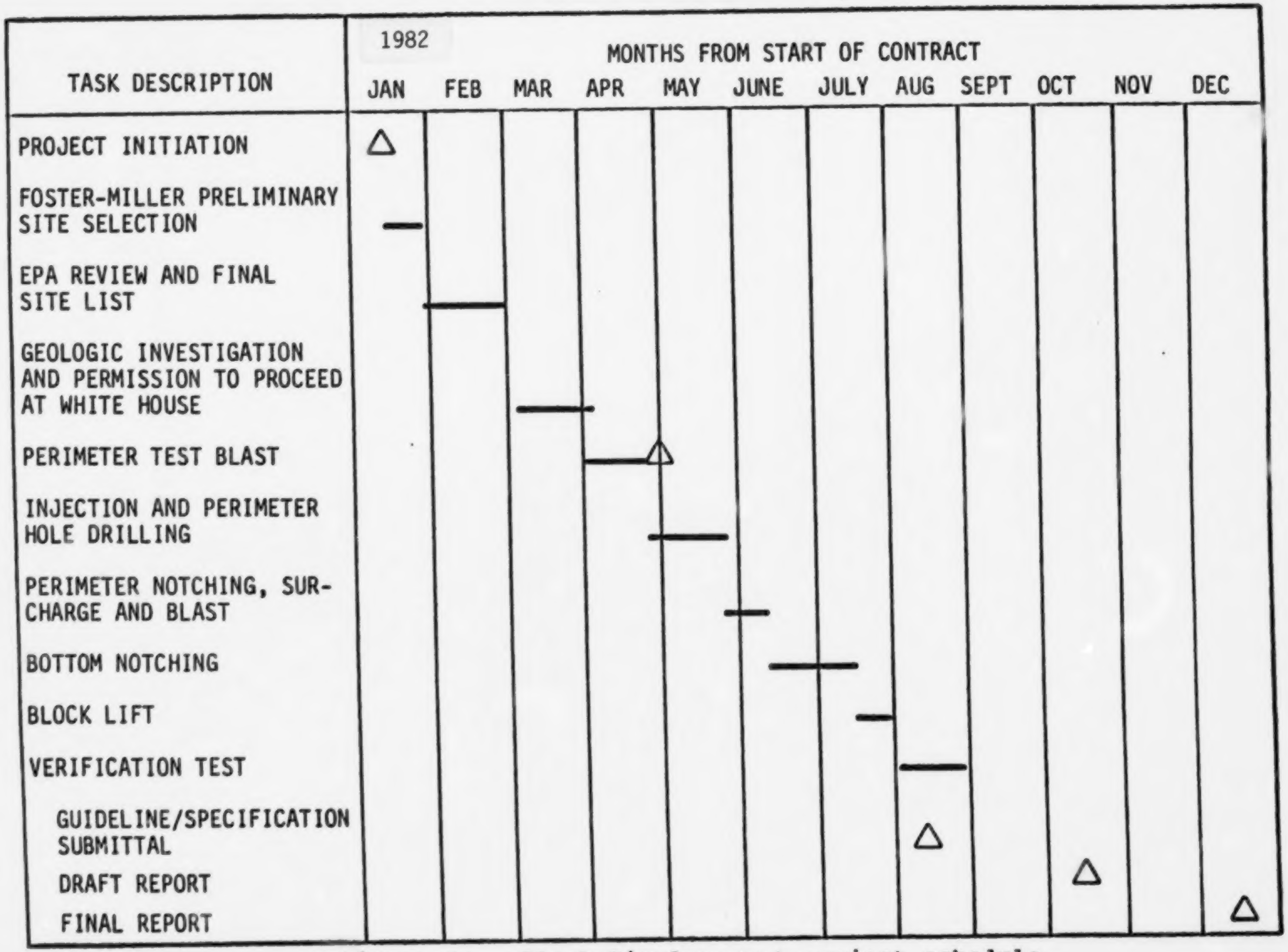


Figure 10. Block Displacement project schedule.

Access Criteria

- Site preparation possible during winter months
- Reasonable vehicular access
- Approximately 40,000 ft^2 of uncontaminated land available for demonstration adjacent to the waste site
- No remedial action initiated at the waste site
- No interference with timely access to the site due to litigation regarding site cleanup responsibility
- No volatile or explosive materials at the waste site.

Geologic Criteria

- Site located in stratified soil
- Site surface not marshy or covered with water
- Site surface reasonably flat
- No major geologic discontinuities in region of planned test
- No major sources of slurry loss in vicinity of anticipated perimeter or bottom surface of block.

These restricting criteria were for the demonstration site only and are not necessarily restrictions for future Block Displacement operations.

Immediate accessibility was deemed necessary to meet the tight 6-month schedule dictated by the pending EPA publication of a "User's Guide for Evaluating Remedial Action Technologies." In order to include Block Displacement in this document, specifications had to be presented to EPA by mid 1982. Specifications following the user's guide format were submitted on 11 August 1982 in time for review and inclusion in the publication (11)

To meet the above deadline, the field demonstration had to be initiated in late winter, thus excluding northern sites where weather conditions could still be too severe. This exclusion eliminated 30 percent of the 114 sites. Additional sites were excluded based on other access criteria presented above.

Selection Process

An extensive survey was carried out by telephone and written communication with regional, state and local agencies to obtain additional information on the remaining sites. The following federal agencies were contacted for detailed topographic, geologic, and hydrological site data.

- EPA Regional Offices
- U.S. Geologic Survey
- U.S. Department of Agriculture Soil and Conservation Service.

The following agencies were also contacted:

- Arkansas – Department of Pollution Control and Ecology
- Florida – Bio Environmental Services
  - Bureau of Geology
  - Department of Environmental Regulation
  - Department of Natural Resources
- Indiana – State Board of Health, Division of Land Pollution Control
- Kansas – Department of Health and Environments
- Kentucky – Natural Resources and Environmental Protection Cabinet, Waste Management Division
- Missouri – Department of Natural Resources
- New Jersey – Department of Environmental Protection
- Oklahoma – Industrial and Solid Waste Service, State Department of Health
- Tennessee – Solid Wastes Management Division, Department of Public Health
- Texas – Department of Water Resources.

Geologic and hydrological criteria were used to further reduce the list of acceptable sites and finally to rate the remaining sites in order of desirability.

Sites with excessive water, such as swampy areas, were eliminated from further consideration. Sites with a high risk of slurry loss or discontinuous stratigraphy were also eliminated. Risk of slurry loss is high in formations containing solution channels, such as Karst limestone or deposits containing excessively coarse gravel often found in river bed depositions. Slurry loss becomes a concern only when these geologic conditions are located in the region of seal placement.

A list of 16 groups of promising sites was tabulated for comparison and submitted to EPA for review. These are listed in Table 5. EPA site selection evaluation included litigation considerations, review by the appropriate section chief, and consideration of state cooperative agreements. By means of this evaluation process, EPA reduced this list to three acceptable candidate sites:

- Arkansas City Dumpsite; Kansas
- Whitehouse Oil Pits; Florida
- North Hollywood Dump; Tennessee.

EPA also suggested consideration of two additional sites previously excluded by FMI. These were:

- Nashua; New Hampshire
- Valley of the Drums, Kentucky.

Additional communication with local agencies aware of the specific conditions at each of the above sites indicated that the Whitehouse site offered the most promising geology.

Site Description

The Whitehouse site is relatively flat terrain composed of marine sediments of silty sand in excess of 100 ft overlaying limestone bedrock. The silty sand appeared to be sufficiently stratified (see Table 6) to be compatible with Block Displacement. Groundwater level in the area varies from 2 to 5 ft, and local drillers indicated that a thick hardpan layer existed at a depth of approximately 20 ft.

The Whitehouse site was visited on 24 February 1982 and a meeting was held at the Florida State Department of Environmental Regulation. Interested federal, state and local agencies were in attendance, as well as property owners of the Whitehouse Oil Pits and adjacent lands.

Based on the field inspection and results from earlier geophysical studies, which indicated that contaminants were migrating to the northwest, land adjoining the south side of the pits appeared most suitable for the Block Displacement demonstration. As shown in Figure 11, the block center was located approximately 200 ft from the edge of the oil pits

TABLE 5. SITE SELECTION DATA

Site	Contacts	Soil profile	Depth of bedrock (ft)	Ground-water table (ft)	Bedrock type and condition	Topography and surface geology	Site area (acres)	Site access and facilities	Site ownership	Notes
Arkansas										
Fritt Industries, Walnut Ridge	Doice Hughes, 501-562-7444 Arkansas Department of Pollution Control and Ecology, 8001 Natison Drive Little Rock, AK 72209	Dune sand/terrace deposits/15 ft/ silts/shale?	~30		Stanley shale?	Flat 0% grade				
Florida										
Bellwood, Orange Tower Chemical, Clermount	Florida State Geologist Bud Hendrie, 904-488-4191									
Sapp Battery Salvage, Jackson County	Sam Johnston, 904-488-0300 Florida Department of Environmental Regulation, Solid Waste Sect., 2600 Blair Stone Road, Talahassee, FL									
Taylor Road Landfill, Tampa Timber Lake Battery Disposal, Tampa Reeves Southeastern, Tampa	Sam Johnston, 904-488-0300 Florida Department of Environmental Regulation, Solid Waste Sect., 2600 Blair Stone Road, Talahassee, FL									
Alpha Chemical Co., Galloway	Sam Johnston, 904-488-0300 Florida Department of Environmental Regulation, Solid Waste Sect., 2600 Blair Stone Road, Talahassee, FL									
Whitehouse Waste Oil Pits Coleman-Evans Wood Preserving Pickettville Road Landfill Whitehouse/Jacksonville	Sam Johnston, 904-488-0300 Florida Department of Environmental Regulation, Solid Waste Sect., 2600 Blair Stone Road, Talahassee, FL	Sands, clays, sandy clays bedded to a depth of 100 ft	~100	~5	Floridan aquifer at ~43 ft = permeable limestone			Good	Abandon State takeover	Looks excellent
Indiana										
Seymour Recycling Co., Seymour	Karen Evans, 317-633-0100 Board of Health/Pollution Control Division or EPA (not contacted) Beverly Kush, 212-886-7572	? Confined aquifer at 20 ft								See E.S.E. F.I.T. team reports
Kansas										
Arkansas City Dump, Arkansas	John Goetz, 913-862-9360-297 Department of Health and Environment, Topeka	Silts, clays, arkosic S&G soils, sandy loam		~10-30						

TABLE 5. SITE SELECTION DATA (Continued)

Site	Contacts	Soil profile	Depth of bedrock (ft)	Ground-water table (ft)	Bedrock type and condition	Topography and surface geology	Site area (acres)	Site access and facilities	Site ownership	Notes
New Jersey										
Kin-Buc Landfill		10 ft marshfill/ 20 ft sand and gravels/shale	>30	0	Shale					
Burut Fly Bog		Sandy soil over silty sand					2			
Bridgeport Rental and Oil		Sand and gravel over less permeable soils								No room on site
Spence Farm Pijack Farm Upper Freehold Goose Farm										See State D.E.P.
Lipari Landfill		20 ft sand and gravel over silty zone								No room on site
Oklahoma										
Criner Waste Disposal Criner	Al Coulter, 405-271-5338 Health Department Industrial Waste Division, Oklahoma City, OK 73152, P.O. Box 53551	Clay sand/sandstone loose/shaley clay/sandstone/...+- silty clay, fine sands, shale clay base	>30		Red clayey shale slightly moist, very hard medium plasticity	20 ft vertical elevation in 600 ft site on ridge of hill steepest nearby grade 5% grade/ 3% site grade				Problem may be surface runoff
Tennessee										
North Hollywood Dump, Memphis	Becky Harris, 615-741-3424 Water Quality, Solid Waste Manager									
Texas										
Sikes Disposal Pits, Crosby	Dwite Hoening, U.S. EPA 214-767-2624	Sand and gravel river deposits	>30	5000 - 2000		Flat 20 ft of vertical elevation on 4000 ft site, 1/2% grade				
Bioecology Systems, Inc. Grand Prairie	Dwite Hoening, U.S. EPA 214-767-2624	? Lake/stream/swamp								
New Jersey										
● Price landfill ● Chemical control ● Lone pine										All small sites

TABLE 6. GEOLOGIC LOG AT WHITEHOUSE, FL, OIL SLUDGE PITS

Description	Depth (ft)
Black silty sand, with trace of clay (fill)	0 to 7
Very fine to fine, dark gray sand, oil matrix, with traces of silt and clay	7 to 17
Very fine to fine, dark brown sand, with traces of silt and clay	17 to 22
Very fine to fine, dark brown to black sand, some cementation, with trace of silt	22 to 27
Very fine to fine, reddish brown sand	27 to 31
Very fine, olive green sand, with traces of silt	31 to 41
Very fine, silty, light gray sand	41 to 47
Very fine, greenish gray sand	47 to 54
Very fine, light gray sand, with traces of silt and clay	54 to 74
Very fine, green sand, with light to medium gray shell fragments interbedded with clay and silt	74 to 84
Silty green clay with traces of shells and very fine sand, with one thin bed of weathered coquina at 114 to 116 ft of length	84 to 120

berm, in a clearing between larger trees and adjacent to an unimproved access road. Permission to use the land was obtained from the property owner, and necessary permits were obtained to proceed with exploratory drilling and groundwater chemical analysis.

Three criteria had to be met prior to proceeding with the demonstration at the Whitehouse Oil Pits site:

- The demonstration site must be free of contaminants migrating from the oil pits
- The stratigraphy must be relatively continuous and horizontal
- The use of the site must meet the approval of both the State of Florida and the EPA.

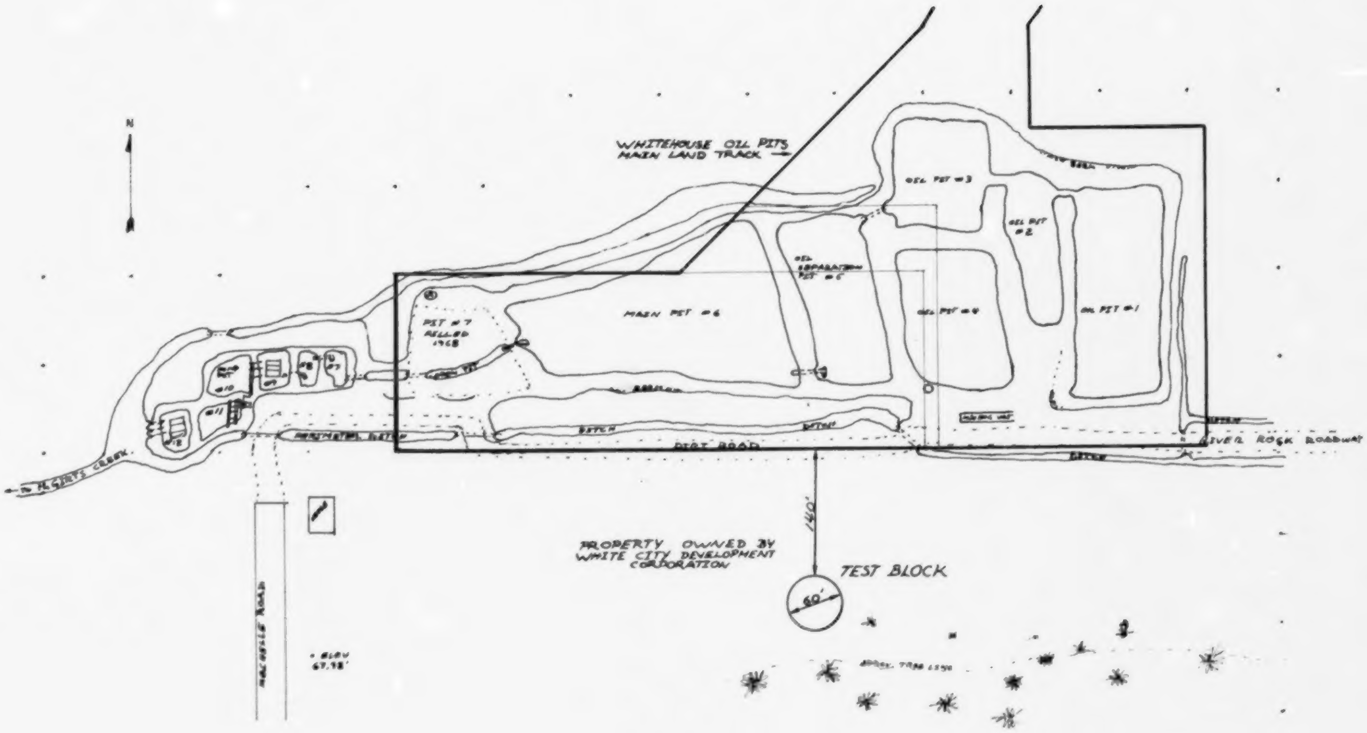

N
WHITEHOUSE OIL PITS
MAIN LAND TRACK
OIL PIT #3
OIL PIT #2
OIL PIT #1
OIL PIT #4
OIL SEPARATION PIT #5
MAIN PIT #6
PIT #7 FILLED 1968
#8
#9
#10
#11
#12
PERIMETER DITCH
DITCH
DIRT ROAD
RIVER ROCK ROADWAY
TO H. GIRTS CREEK
ROAD
ELEV 67.78'
140'
PROPERTY OWNED BY WHITE CITY DEVELOPMENT CORPORATION
TEST BLOCK
60'

Figure 11. Whitehouse Oil Pits site map
(scale 1 in. = 200 ft).

Three exploratory holes were drilled and continuously sampled, triangulating the demonstration site (see Figure 12). Holes T-1 and T-2 were driven to a depth of 30 ft with continuous split spoon samples driven in 2-ft increments. In hardpan regions, continuous split spoon sampling was reduced to 1-ft increments when necessary due to high penetration resistance. Hole T-3 was drilled and sampled to a depth of 60 ft in a like manner. The soil profile was categorized, and standard penetration resistance was recorded in all holes (see Figure 13).

Hardpan was encountered in all three holes at approximately 10-ft depth and continued to between 20 and 25 ft underlaid by unconsolidated brown sand. The contact between hardpan and brown sand below was a gradual transition of interbedded layers and lenses of the two soils.

Water samples were taken at the surface, at 5-ft depth near the oil pits and at 20 ft depth from drill hole T-2. Chemical analysis of these samples (see Table 7) indicated low pH, but no indication of contaminant migration from the oil pits.

The transition zone between hardpan and underlying brown sand appeared to be a suitable medium for inducing bottom fracture. A block diameter of 60 ft and depth of 23 ft were selected based on this geology. Permission was obtained from the State of Florida and EPA to proceed with the demonstration following procurement of hazardous waste liability insurance.

5.2 CONSTRUCTION

The field operation involved three distinct operations:

- An explosive blast in three adjacent test holes to determine perimeter fracture performance
- Preparation of the block by drilling and slotting 32 perimeter holes, and drilling and casing 7 slurry injection holes
- Fracturing both the bottom and the perimeter, and lifting the block.

Perimeter Test Blast

Prior to commencing with the block perimeter and injection hole drilling, three test holes were drilled to a depth of 27 ft at the prescribed 14 degree angle off vertical. The three holes were of 6 in. diameter and spaced at 3-ft and 6-ft intervals along a straight line. They were drilled in an area apart from the proposed test block as indicated in Figure 12. This drilling was done to gain experience in angled drilling with the mobile rig, to experiment with hole slotting tools,

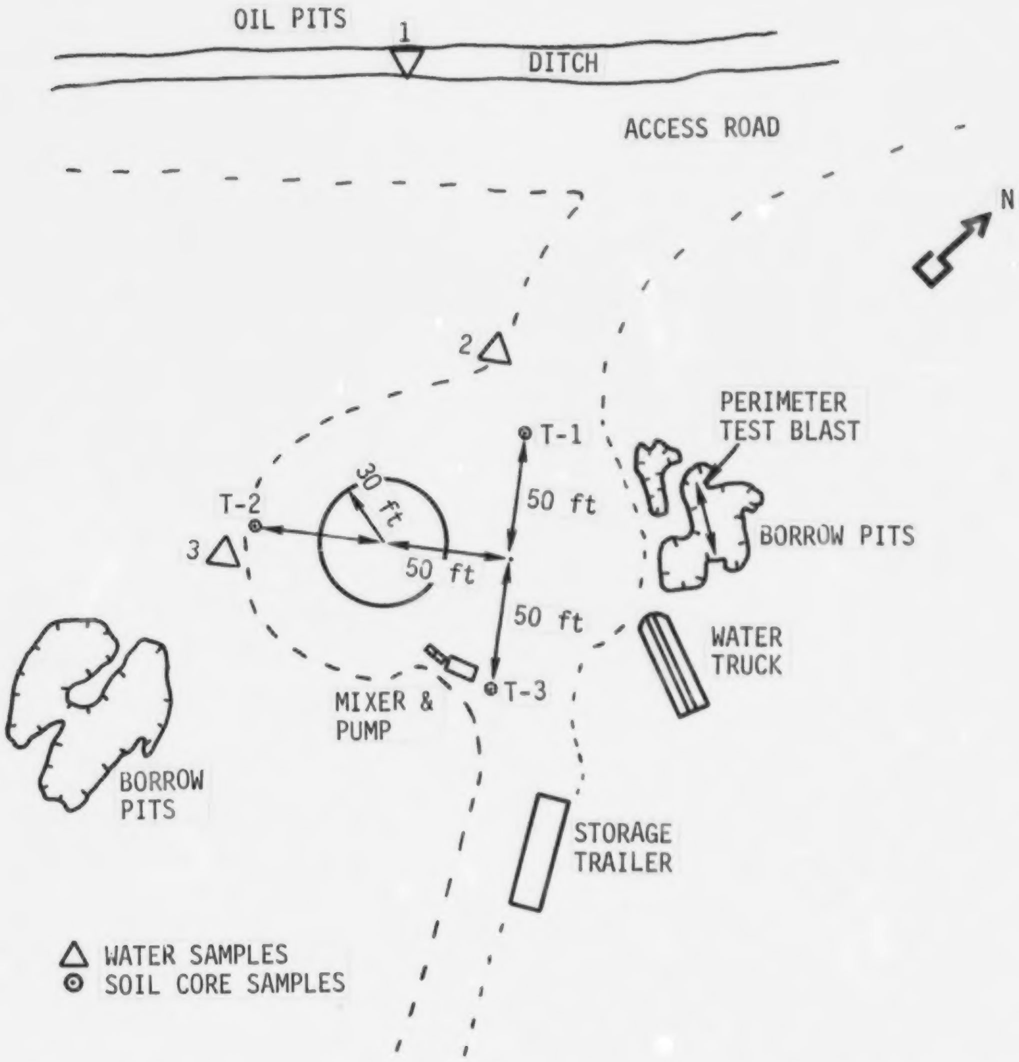

OIL PITS
1
DITCH
ACCESS ROAD
N
2
PERIMETER
TEST BLAST
T-1
30 ft
T-2
50 ft
3
50 ft
BORROW PITS
50 ft
WATER
TRUCK
T-3
MIXER &
PUMP
BORROW
PITS
STORAGE
TRAILER
△ WATER SAMPLES
⊙ SOIL CORE SAMPLES

Figure 12. Demonstration site plan.

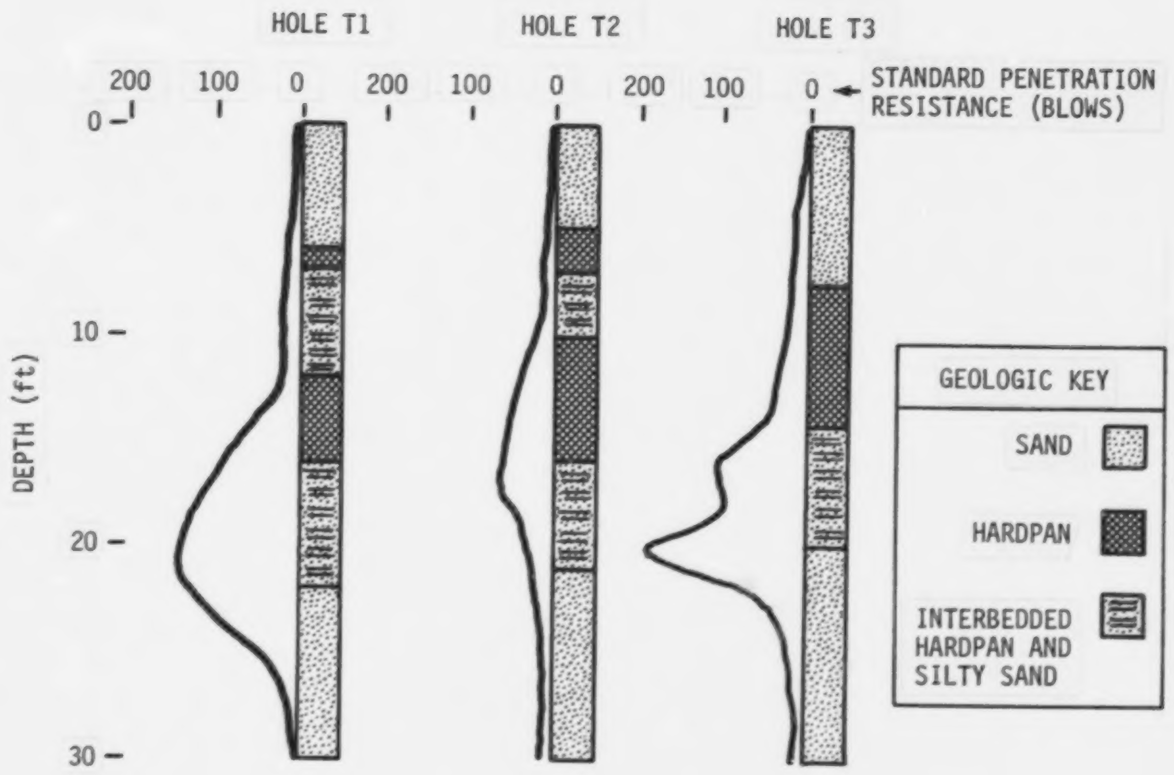


Figure 13. Block Displacement demonstration geology.

TABLE 7. CHEMICAL ANALYSIS OF DEMONSTRATION SITE GROUNDWATER

Sample No. (located on Figure 4)	1	2	3
Depth	Ditch	4 ft	20 ft
Date	3/23/82	3/23/82	3/29/82
pH	1.92	4.26	5.75
Phenol, mg/l	-	0.0278	0.0202
Iron as Fe, mg/l	-	10.27	13.10
Lead as Pb, mg/l	-	0.143	0.166
Free mineral acidity as $CaCO_3$, mg/l	2,037.5	22.5	-
PCB, mg/l	<0.007	<0.007	-
Sulphate, mg/l	-	26.01	0.18

and to use these holes to conduct an experimental blast for joining the slot tips. The hole spacing and explosive charge load would determine the ultimate number of block perimeter holes required. Twenty-six feet of 50-grain/ft Prima-cord™ explosive was placed to within 1 ft of the top of each hole, and 10 ft was overlapped at the bottom, as shown in Figure 14, to give this portion of each hole a 100-grain/ft load. The cord was capped at the bottom of each hole using a special cap insertion tool. Post-blast inspection showed that the fractures between the 3-ft spaced holes clearly joined; and that the 6-ft spaced holes had their slots extended far enough to join but not in a straight line, thus making verification difficult.

Figure 15 shows a cross section of the two hole slotting tools employed prior to blasting. The driller's 140-lb hammer dropped 30 in. could drive the 3-in. wing tool but not the 6-in. wing. Although the charge level used appeared sufficient to join even the 3-in. wing slots at the 6-ft hole spacing, FMI elected, as a means of additional assurance of hole connection, to contract a larger hammer to drive a 6-in. wing slotting tool during the major block work. Thus, it was decided that the test explosive charge level was sufficient for the major block perimeter blast, and that a total of 32 perimeter holes spaced at intervals of approximately 6 ft was reasonable.

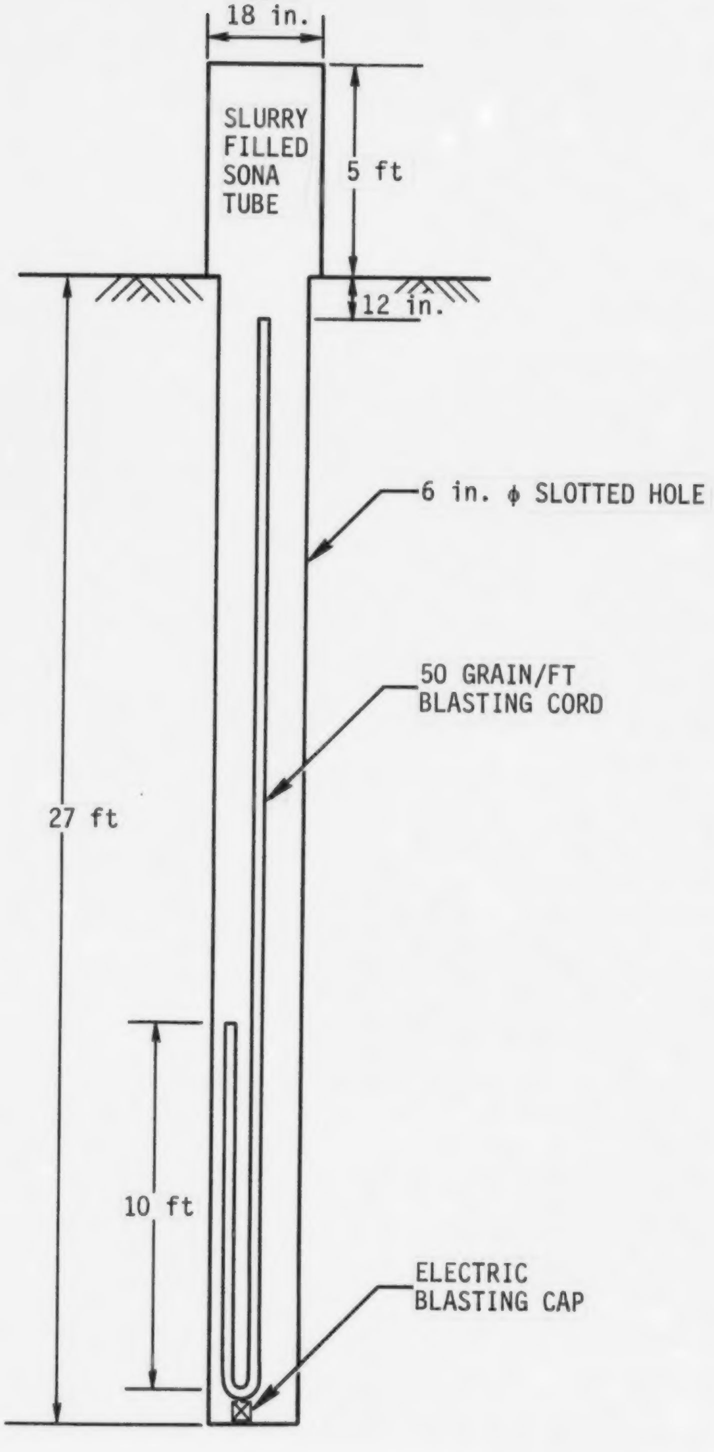
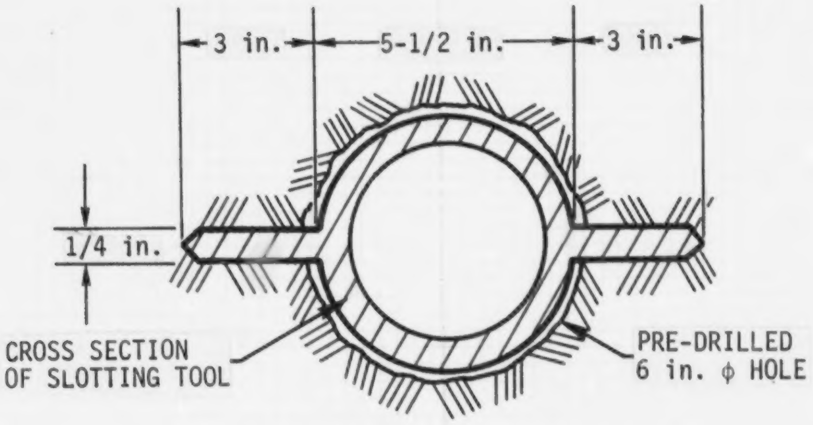
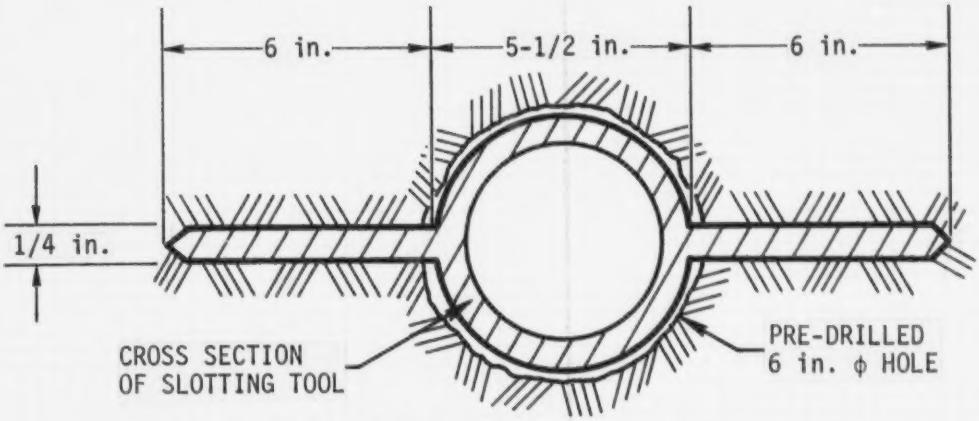

18 in.
SLURRY
FILLED
SONA
TUBE
5 ft
12 in.
6 in. ϕ SLOTTED HOLE
50 GRAIN/FT
BLASTING CORD
27 ft
10 ft
ELECTRIC
BLASTING CAP

Figure 14. Perimeter hole blast loading.


3 in.
5-1/2 in.
3 in.
1/4 in.
CROSS SECTION
OF SLOTTING TOOL
PRE-DRILLED
6 in. ϕ HOLE

COULD BE DRIVEN WITH DRILLER'S HAMMER


6 in.
5-1/2 in.
6 in.
1/4 in.
CROSS SECTION
OF SLOTTING TOOL
PRE-DRILLED
6 in. ϕ HOLE

COULD NOT BE DRIVEN WITH DRILLER'S HAMMER

Figure 15. Cross sections of experimental slotted holes.

Injection Hole Drilling

Seven 23-ft deep injection holes, placed as shown in Figure 16, were to be cased with 6-in. PVC pipe, and hence required a larger bit for drilling. An 8-in. bit was fabricated and, with the exception of encountering occasional tree roots, the drilling went quite smoothly. PVC pipe in 25 ft lengths was installed in each hole so that the last 2 ft protruded above ground. Each hole was also bottom grouted using portland cement to assure a reasonable casing seal. Two cubic feet of grout was placed in each hole displacing the drilling mud. The PVC casing was then pressed through the wet grout using the drill rig downhaul. The cement was later drilled through to earth, and the casings were temporarily capped.

Perimeter Hole Drilling

The experience gained during test hole drilling proved very helpful for the perimeter hole drilling. At each of the 32 hole locations shown in Figure 16, the drill rig was positioned on the block perimeter and tilted to the desired 14 degree angle by extending the appropriate hydraulic stabilizer jack inside the block. Subsequent measurement indicated that the off vertical angle varied from 12 to 14 degrees around the block. The 6-in. drill bit was used, and five to seven holes were completed each day. A fresh batch of 10 percent bentonite by weight mud was left in each hole to ensure against hole collapse.

Perimeter Slotting

For the perimeter slotting operation, a pile driver was brought to the site and two new and different slotting tools were fabricated, as shown in Figure 17. Because of the relatively large surface area and general geometry of the disc slotter, the impact force required to drive it was so great that the pipe bent severely before the tool reached the bottom of the first hole. A second tool with a reduced area, diamond-shaped slotter was fabricated using a single length pipe. The thickness of the slot blades was also reduced by half for this tool. Using the modified diamond slotter, the pile driver heads were angled at 14 degrees off vertical, as shown in Figure 18. The pile driver delivered 700- to 1,400-ft-lb blows to the slotting tool, typically driving the tool 6 in./blow. All 32 perimeter holes were slotted in just over 3 days time.

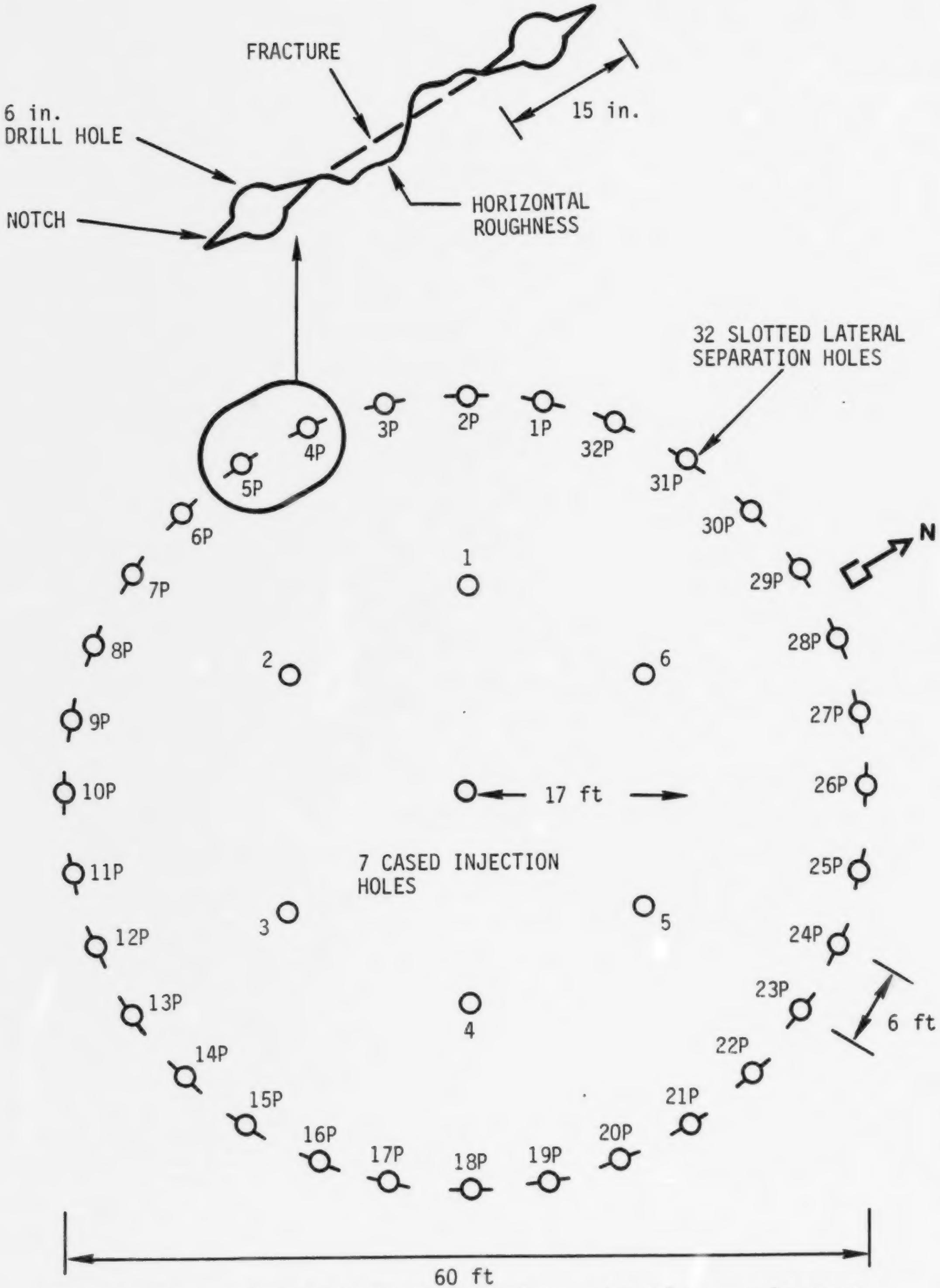
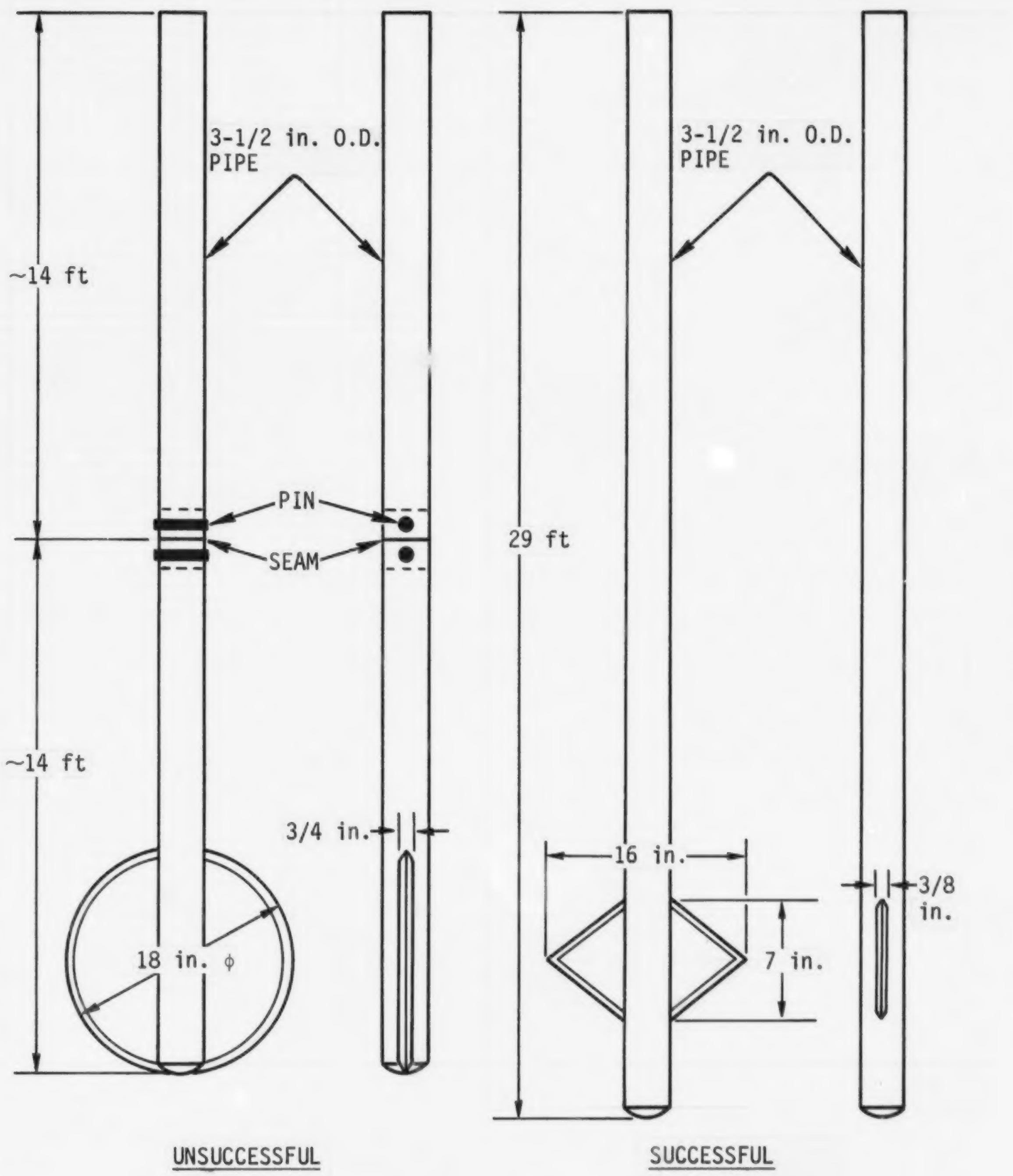

FRACTURE
6 in.
DRILL HOLE
NOTCH
15 in.
HORIZONTAL
ROUGHNESS
32 SLOTTED LATERAL
SEPARATION HOLES
N
1P
2P
3P
4P
5P
6P
7P
8P
9P
10P
11P
12P
13P
14P
15P
16P
17P
18P
19P
20P
21P
22P
23P
24P
25P
26P
27P
28P
29P
30P
31P
32P
1
2
3
4
5
6
17 ft
7 CASED INJECTION
HOLES
6 ft
60 ft

Figure 16. Block Displacement demonstration perimeter and injection hole spacing.


~14 ft
~14 ft
3-1/2 in. O.D. PIPE
PIN
SEAM
3/4 in.
18 in. ϕ
29 ft
3-1/2 in. O.D. PIPE
16 in.
7 in.
3/8 in.

UNSUCCESSFUL

DISC SLOTTER

SUCCESSFUL

DIAMOND SLOTTER

Figure 17. Perimeter hole slotting tools.

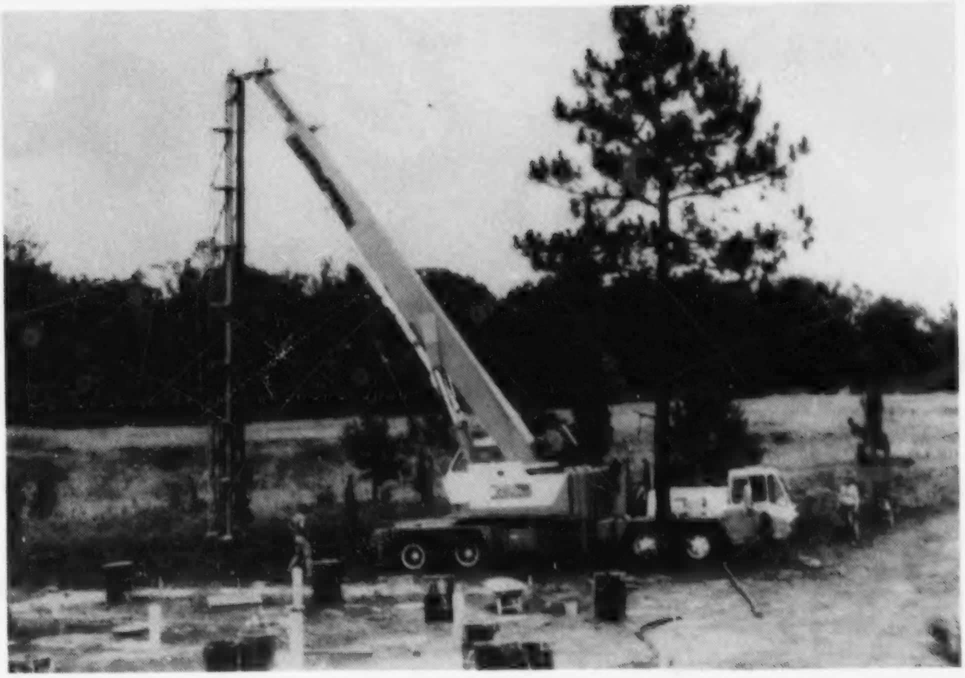


Figure 18. Perimeter slotting tool driving operation.

Perimeter Fracture

In preparation for the perimeter fracture blasting, a 5-ft long, 18-in. diameter "sona tube" (tubular heavy gauge cardboard cement form) was placed on-end over each perimeter hole, as shown in Figure 19. Each tube was then filled with a very heavy barite (specific gravity of >2.0) mud, which acted as a surcharge to prevent mud loss during the blast, and to force the mud in each perimeter hole out into the separation created by the blast.

With this accomplished, the explosive charges were loaded into each hole in the same manner as for the experimental blast (i.e., 50 grain/ft, with Prima-cord™ overlapped for the bottom 10 ft of hole). On 8 June at 8:38 p.m., all 32 charges were set off simultaneously and 4 of the 32 holes misfired. The misfired holes are identified as 5p, 22p, 28p, and 31p on Figure 16. None of the four misfired holes were reblasted prior to the initial block lift. Several sona tubes were damaged by the blast and were replaced. A detectable perimeter fracture appeared to run around almost the entire circumference of the block at the surface, as indicated in Figure 20. A piece of spring steel was used to probe the fracture to verify hole connection. This device confirmed that most perimeter holes did join down to a depth of several feet, beyond

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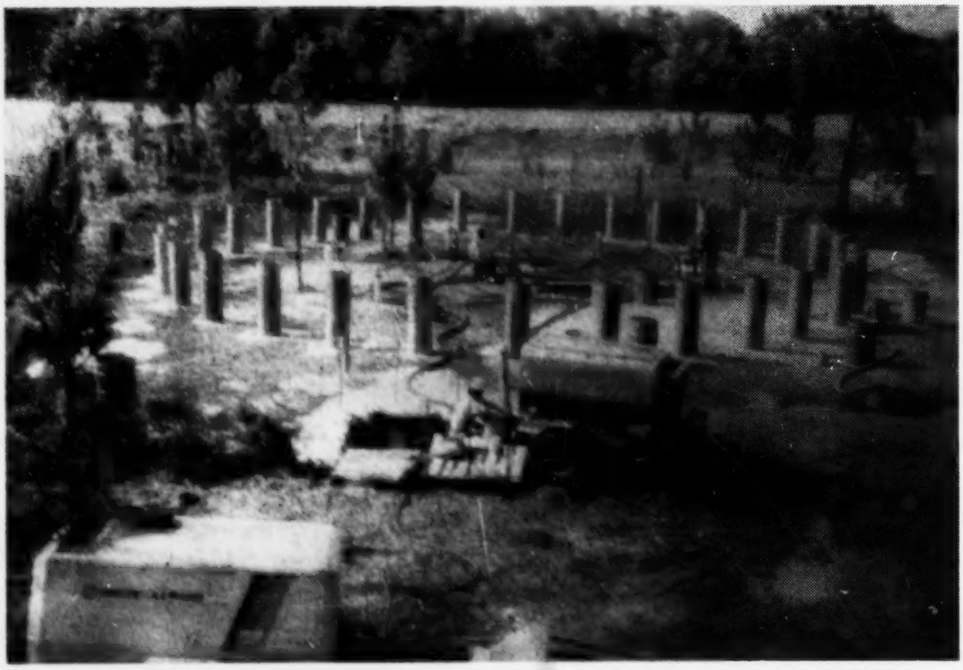


Figure 19. Surcharged perimeter holes ready for explosive blast.

Figure 20. Surface fracture induced by perimeter blast.

which the spring steel could not penetrate the fracture. The blast-induced fracture appeared reasonably continuous.

Bottom Notching and Fracture

A number of alternative bottom notching techniques were considered, including mechanical notching and one that combined high-pressure air with an erosive sand water slurry in the jet notching process. System complexity and potential problems with maintaining control on the air pressure required for stabilizing the notch opening led to the consideration of simpler systems.

The chosen system employed a high-pressure, slurry jet oriented horizontally and rotated at the bottom of the hole to erode a pancake-shaped notch. A properly designed slurry can optimize notch erosion, remove the cuttings and minimize leakoff into the soil. The high-pressure jet can create notches of larger diameter than are practical with a mechanical notching tool. Initially a 2-percent bentonite slurry was jetted in a slurry medium in all seven injection holes yielding notches 2 ft in diameter.

This bottom notch diameter was determined both indirectly by measuring the volume of cuttings removed during notching and directly by means of a downhole caliper. The volume of cuttings was measured by recording the change in height of settled material in a 55-gal drum used as a settling tank. The downhole caliper measured the insertion distance of a spring steel tongue which was forced into a horizontal orientation over a series of rollers when engaged. This notch caliper is shown in Figure 21. The caliper was operated manually from the surface by pushing a sliding rod downward relative to a fixed position caliper body, which could be lowered to the desired depth in the injection hole.

Having determined the notch diameter, it was possible to estimate injection pressure requirements. Based on an average soil unit weight of 135 lb/ft^3 and a depth of 23 ft, the vertical stress due to overburden at the notch depth is 22 psi. An injection pressure in excess of 22 psi was, therefore, anticipated to initiate horizontal separations from the 2-ft diameter notches. Initial injection required pressures in excess of 40 psi to induce slurry flow. These higher than anticipated pressures were attributed to excessive filter cake buildup at the tip of the notch, resulting from slurry leakoff occurring over a period of weeks. It was believed that if fracture propagation was initiated immediately after notching, this filter cake buildup and the associated higher fracture pressure could be minimized. This was verified in injection holes 5 and 4. By renotching and immediately injecting fracturing slurry into each hole, separations

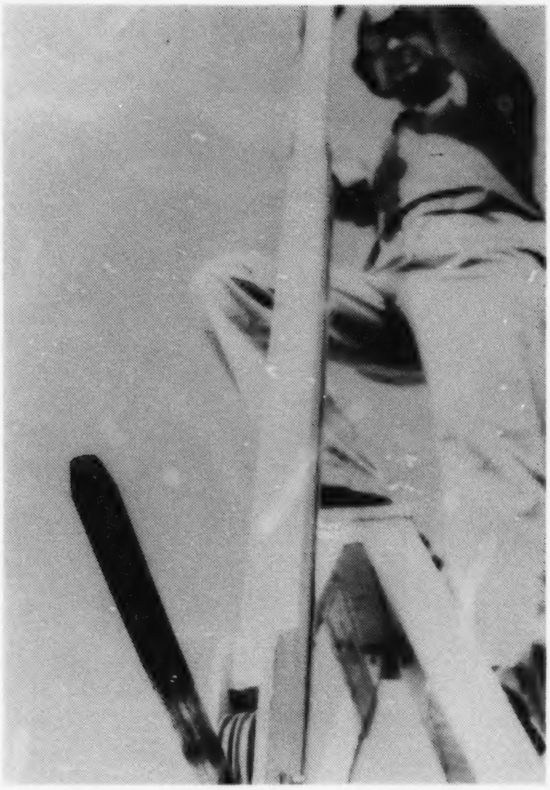


Figure 21. Downhole horizontal notch radius caliper.

were propagated to the closest perimeter hole, as shown in Figure 22, at pressures considerably below the 40 psi required otherwise.

Excessive injection pressures of 30 to 40 psi were required on holes 0, 1, 3, and 6, however, leading to leakage up along the casings. Leakage into the overburden often reached the surface in the vicinity of these injection holes.

Deformation analysis of an infinite half space (as discussed in subsection 4.2) indicated that injection pressure should be inversely proportional to notch diameter. The jet notching system was modified to increase notch diameter to 4 ft. The modified jet system, shown in Figure 23, was designed to erode with a jet of 2-percent bentonite slurry in air. Slurry was pumped down a 2-in. diameter line to a 1/2-in. horizontal jet through the orifice, shown in Figure 24. Slurry, cuttings and excess air then returned up a 1-1/2-in. diameter return line from a sump beneath the jet to a settling tank on the surface. The air medium was maintained by a slow

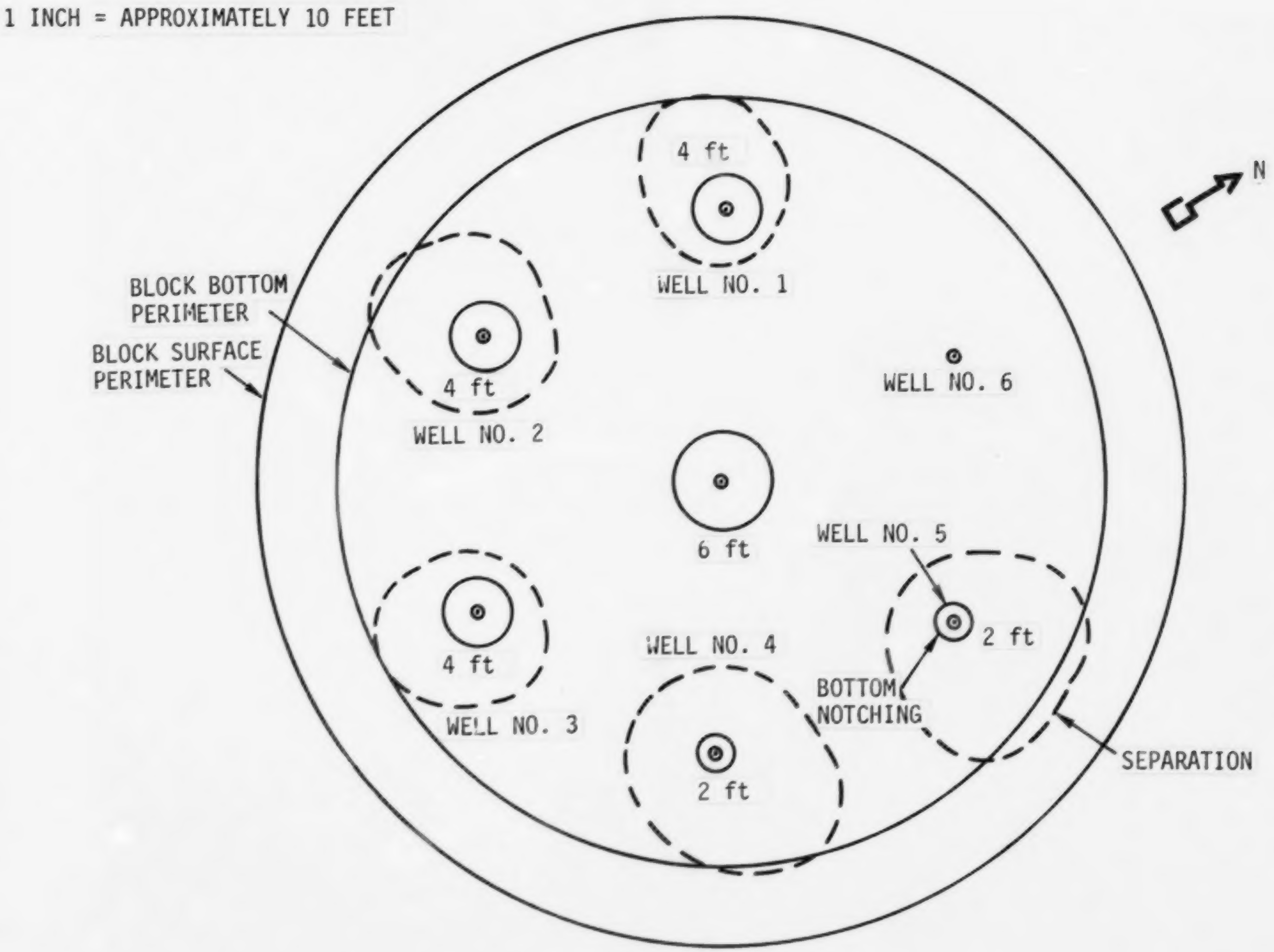

1 INCH = APPROXIMATELY 10 FEET
4 ft
WELL NO. 1
N
BLOCK BOTTOM PERIMETER
BLOCK SURFACE PERIMETER
4 ft
WELL NO. 2
WELL NO. 6
6 ft
WELL NO. 5
2 ft
4 ft
WELL NO. 4
BOTTOM NOTCHING
WELL NO. 3
SEPARATION
2 ft

Figure 22. Plan view of bottom notches and separation propagation.

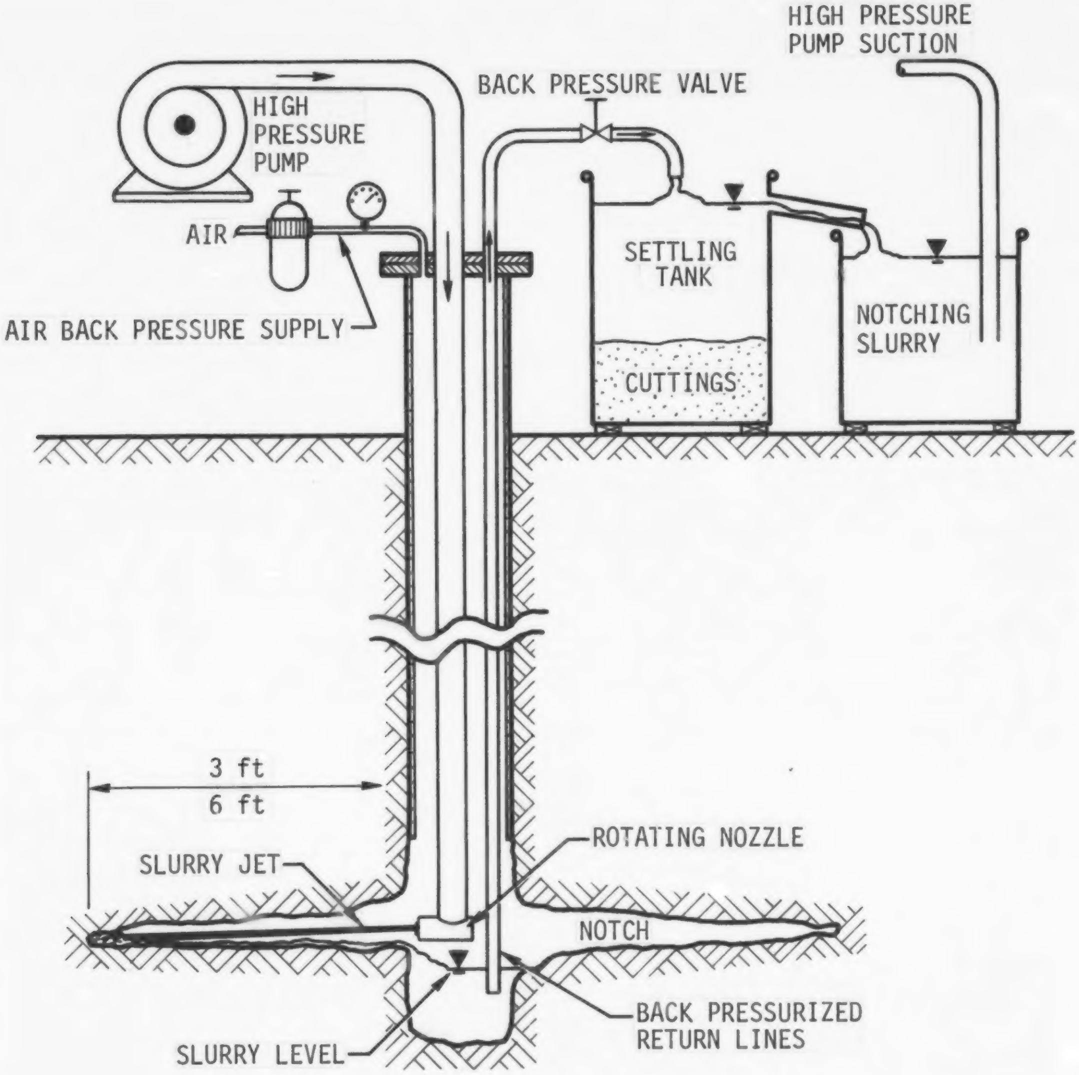

HIGH PRESSURE PUMP SUCTION
BACK PRESSURE VALVE
HIGH PRESSURE PUMP
AIR
AIR BACK PRESSURE SUPPLY
SETTLING TANK
CUTTINGS
NOTCHING SLURRY
3 ft
6 ft
ROTATING NOZZLE
SLURRY JET
NOTCH
BACK PRESSURIZED RETURN LINES
SLURRY LEVEL

Figure 23. Slurry jet in air notching operation.

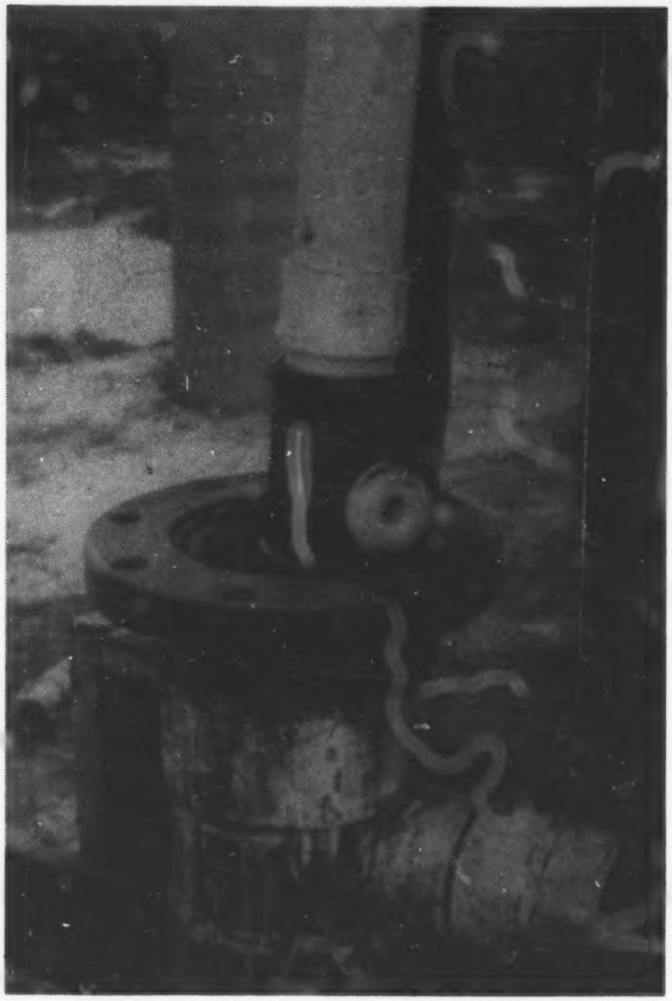


Figure 24. Slurry notching jet tool.

inflow of compressed air at the casing collar. Backpressure was maintained by a flow control valve throttling the return flow at the settling tank. Excess air bubbled into the return line in the sump and was released at the settling tank.

This system was used to notch and propagate separations from injection holes 3, 2, and 1 to the closest perimeter holes (Figure 22). Due to the time elapsed as a result of the above mentioned problems encountered in propagating bottom separations, hole 5 had to be reactivated (notched and fractured).

In the course of modifying the notching system to achieve the desired performance, over 20 leaks to the surface were encountered requiring the development of a routine leak seal-off procedure. Initially, portland cement grout was pumped under low pressure into the leaking injection hole, allowed to set and through drilled in preparation for another notching attempt at slightly greater depth. This operation proved time-consuming and made subsequent notching operations more difficult.

A second method of sealing off leaks was, therefore, adopted and refined. A thick slurry containing swelling particles of varying diameter (oats and grits) was pumped into the leaking injection hole and the injection pressure was gradually increased, allowing these particles to bridge the leak channel and seal off with filter cake buildup. Upon attaining sufficient pressure (35 to 40 psi), the hole was renotched followed by immediate separation propagation.

The sealing technique was time-consuming, but worked well for leaks in all holes except hole 6. Leaks induced at this hole by initial high-pressure (40 psi) injection attempts were first sealed by cement grout. During subsequent attempts to notch and propagate separations using the slurry in air notching tool, a hose break caused total loss of air backpressure which was supporting the notch. The notch collapsed, radically disturbing the ground in the vicinity of the cement grout seal placed earlier and making further attempts at notching fruitless.

The 2 percent bentonite slurry in air notching operation was applied to the central hole but injection pressures again were too high. A high-pressure (150 psi) jet pump, shown in Figure 25, was used to increase the jet efficiency yielding a 6-ft diameter notch at the central hole. Injection then proceeded smoothly at 25 psi with the central hole connecting to each of the intermediate injection holes after 500 gal of slurry had been injected.

At this time, visible upward displacement was measured at several points within the block by means of a surveyor's level located 50 ft beyond the block perimeter. Immediately following this displacement the observed pressure transferred to intermediate injection holes and flow was observed intermittently from various perimeter reservoirs (sona tubes).

Block Lift

A mud distribution manifold was fabricated for both fracturing and lift operations, as shown in Figure 26. A 3-in. diameter inlet port was connected to the outlet of the mud pump, and each valved 2-in. outlet port was connected to an injection hole casing. Each casing had a pressure gauge installed as a means of monitoring injection pressure and as an aid in detecting connections with other holes. Although the

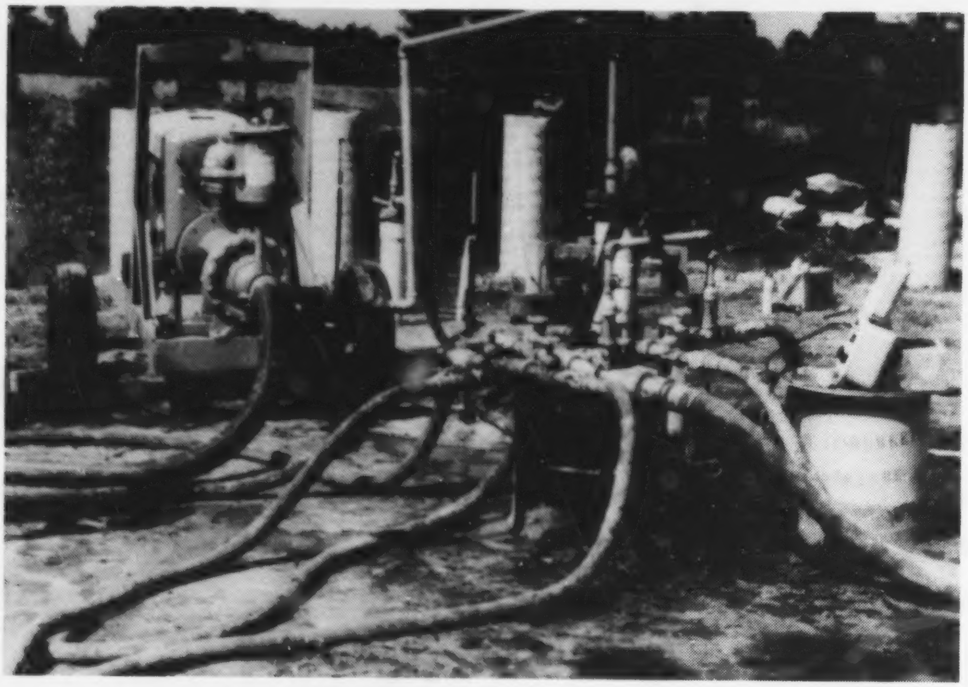


Figure 25. High-pressure jet pump slurry notching system.

manifold permitted mud injection into any number of the seven holes simultaneously, the pumping was usually confined to one of three holes at a time. The hole selected to receive the mud was determined by measurements of lift at certain points on the block using the engineer's level set up outside the block. When lift was observed at an injection point, the mud was then directed to a different injection hole in an attempt to lift the entire block surface as evenly as possible. This process was continued until each injection hole was lifted between 1/32 and 1/16 in. during mud injection.

Although connection to the perimeter is an integral part of completing the bottom fracture, the connection route provides a path of least resistance beyond which the bottom fracture will not propagate until the mud flowing to the surface at the perimeter is plugged off. Following connection from any injection hole to the perimeter, the perimeter hole was watched for excessive flow. If flow at the perimeter approached the rate of injection, the perimeter hole was plugged with 8-ft sections of fence post and/or utility pole stock 8 to 10 ft in length. Five perimeter holes were plugged in this fashion. The slurry flowing out at the perimeter was collected in a channel between two berms encompassing the perimeter and returned to the stock of injection slurry.

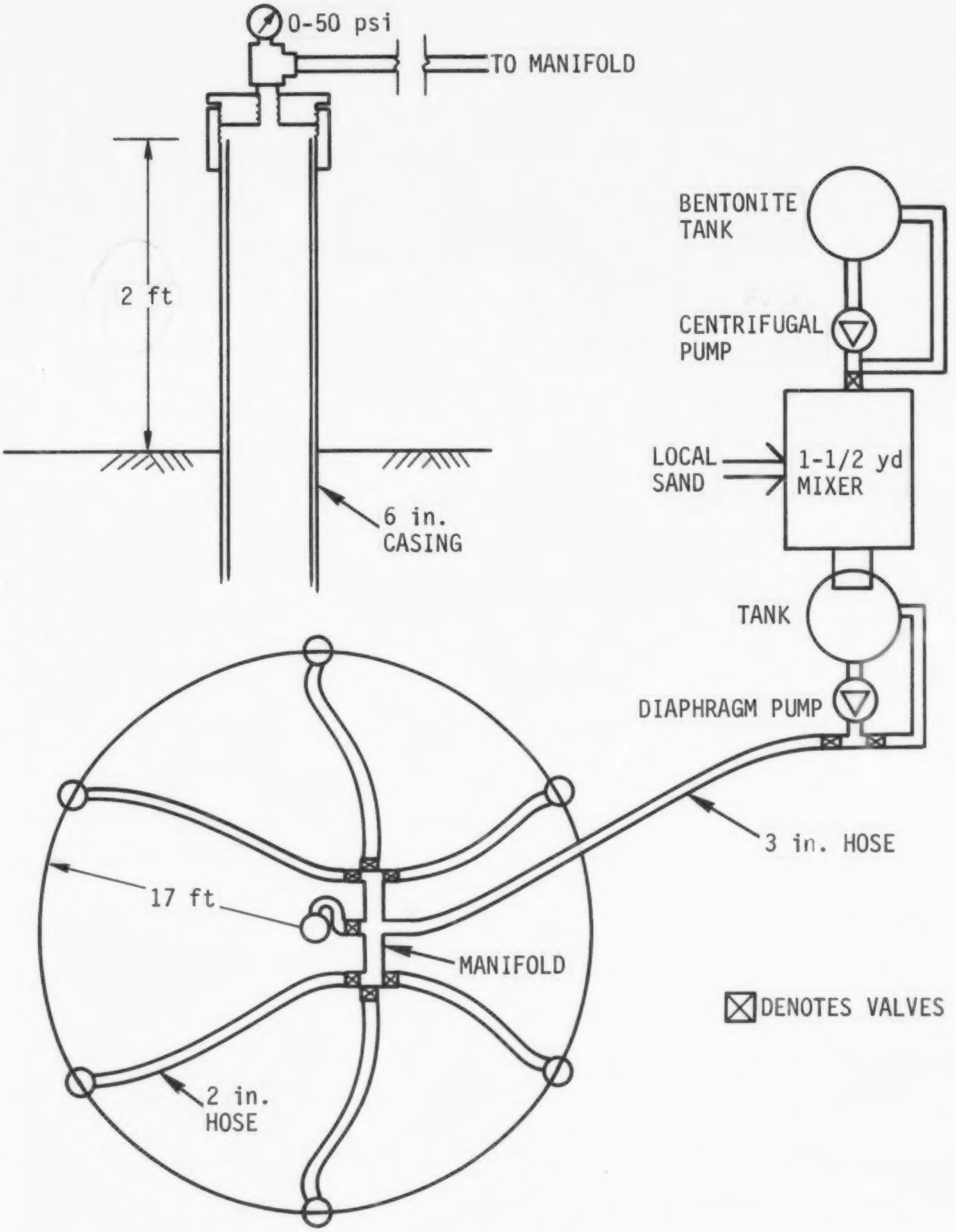

0-50 psi
TO MANIFOLD
2 ft
6 in.
CASING
BENTONITE
TANK
CENTRIFUGAL
PUMP
LOCAL
SAND
1-1/2 yd
MIXER
TANK
DIAPHRAGM PUMP
3 in. HOSE
17 ft
MANIFOLD
DENOTES VALVES
2 in.
HOSE

Figure 26. Slurry injection distribution system.

The first detectable block lift came at injection holes 2 and 3, and at perimeter hole 15 with 1/32-, 5/32-, and 1/32-in. lift, respectively. For hole locations refer to Figure 30 in subsection 6.1. Fracture mud had been pumped into other injection holes, but these were the first to respond.

Once lift was detected, the injection slurry was modified by adding local soil to add weight and reduce cost. The added material was surface excavated, silty sand which acted as an aggregate in the bentonite and water matrix. The resulting slurry has a density approaching 2.0 and is more viscous, having a gel strength of 50 to 100 pascals. Injection pressure responded to the thicker slurry by increasing to a range of 25 to 35 psi.

After several days of pumping, primarily into the central injection hole, some lift had been detected nearly everywhere, but it was becoming apparent that injection holes 2, 3, and later 4 were lifting at a much faster rate than the others. A surface crack, paralleling the perimeter and just outside injection hole 3, began to develop and extend around the inner block towards injection holes 2 and 4. See Figure 33 in subsection 6.2 for location of this surface crack. It was further observed that perimeter hole 15, the one closest to injection hole 3, had stopped lifting and had, in fact, dropped approximately 1/8 in. As the connection had previously been made between injection hole 3 and the perimeter hole 15, it was theorized that this block drop was being caused by some sort of perimeter "hang-up," and not by a lack of horizontal bottom fracture. It was assumed that either the perimeter blast did not completely join the holes along the southwestern edge of the block, or large tree roots or trunks were causing that edge of the block to hang up. To eliminate any doubt concerning the quality of the blast, the perimeter holes were again loaded with explosive, as shown in Figure 27, and the charges were set off on 20 July, while simultaneously pumping mud into injection hole 3. Despite the use of more than twice the load for the reblast, the southwest edge of the block refused to lift. As the pumping continued, the fracture running from injection hole 2 to 4 became an actual "step" of approximately 1 ft difference in elevation, as shown in Figure 28.

Throughout the entire field demonstration described above, data were collected on every phase of the effort. The data collection procedures were continuously revised and the instrumentation modified as experience was gained. The nature of this data and the overall results of the field demonstration are presented in Section 6.

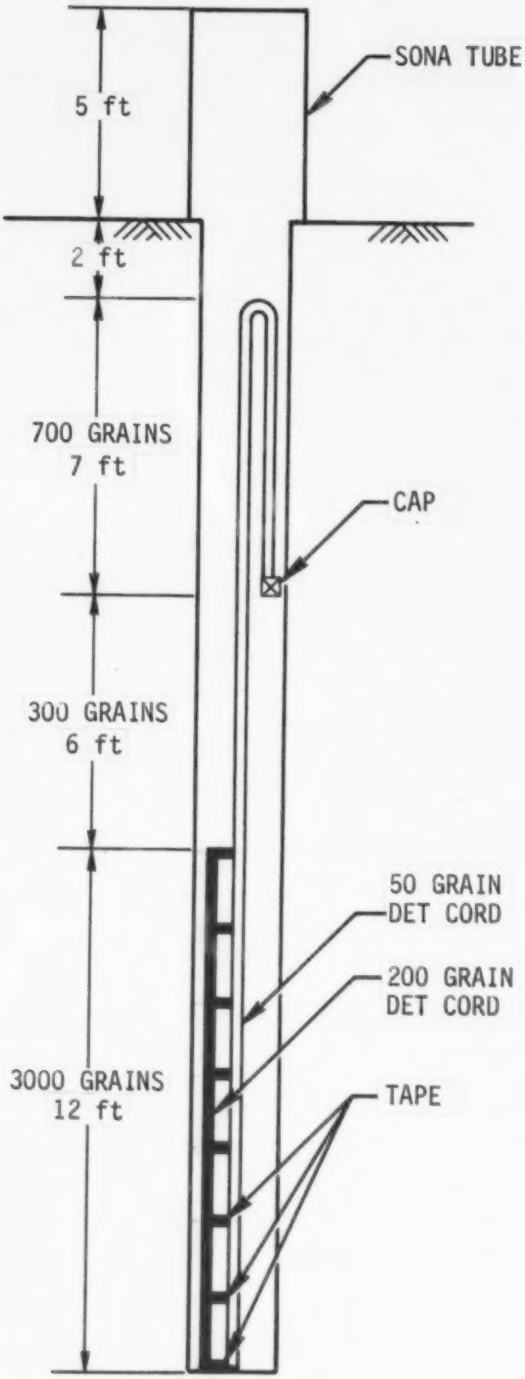

SONA TUBE
5 ft
2 ft
700 GRAINS
7 ft
CAP
300 GRAINS
6 ft
50 GRAIN
DET CORD
200 GRAIN
DET CORD
3000 GRAINS
12 ft
TAPE

Figure 27. Perimeter hole reblast loading.

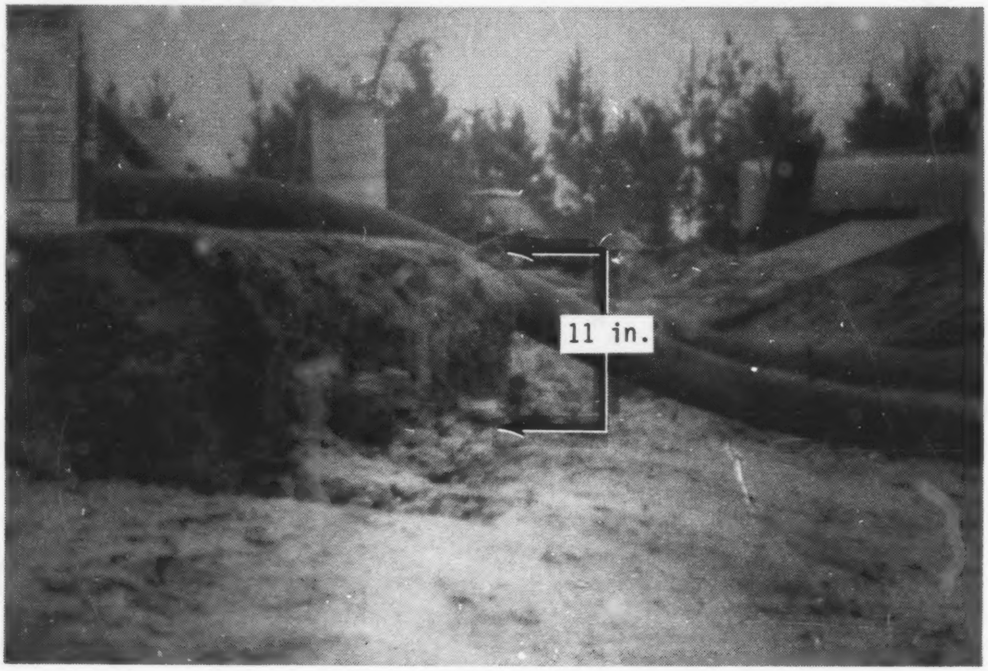


Figure 28. Upward displacement at surface due to block lift.

6. RESULTS OF FIELD DEMONSTRATION

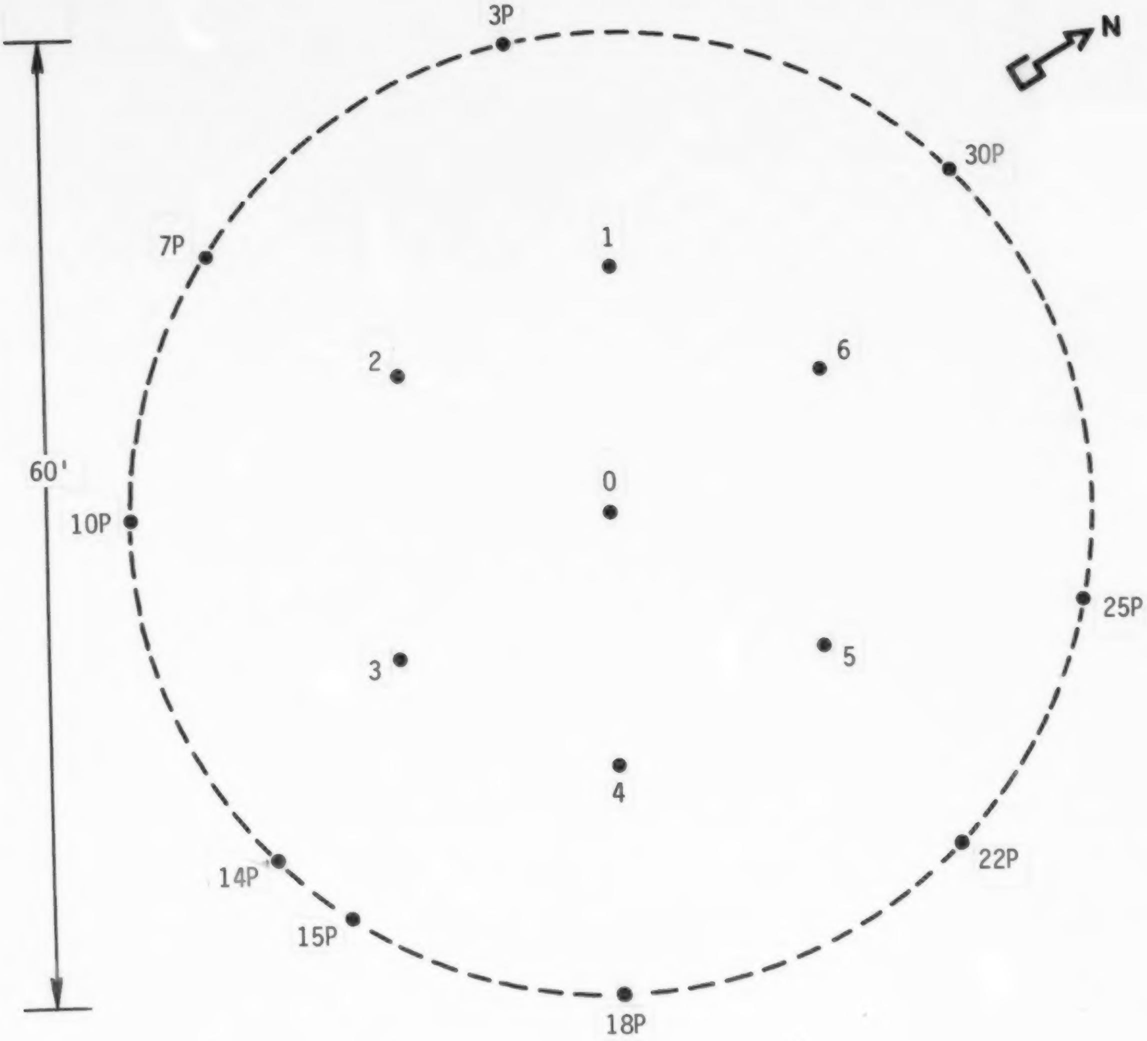
Procedures for accomplishing the Block Displacement have been described in some detail in Section 5. The results of the effort are presented below. A general summary of the results is presented first, followed by detailed discussion of specific features of the demonstration.

6.1 GENERAL SUMMARY

Displacement of the block was monitored by recording the change in elevation of 16 fixed rods located as shown in Figure 29. The total recorded lift in inches at these locations on the block is shown in Figure 30. Elevations were read through a surveyor's level located 50 ft outside of the block perimeter. Additional survey points beyond the block boundary were monitored during a portion of the lift operation to verify that no lift was occurring outside of the perimeter. Survey points 0 through 6 correspond to rods located approximately 3 ft from the injection holes. The remaining nine survey points, 3p through 30p, correspond to rods located just inside the perimeter. These survey point numbers correspond to the closest hole numbered progressively from 1 to 32 in a counterclockwise direction around the perimeter. A detailed discussion of block lift monitoring is presented in subsection 6.2.

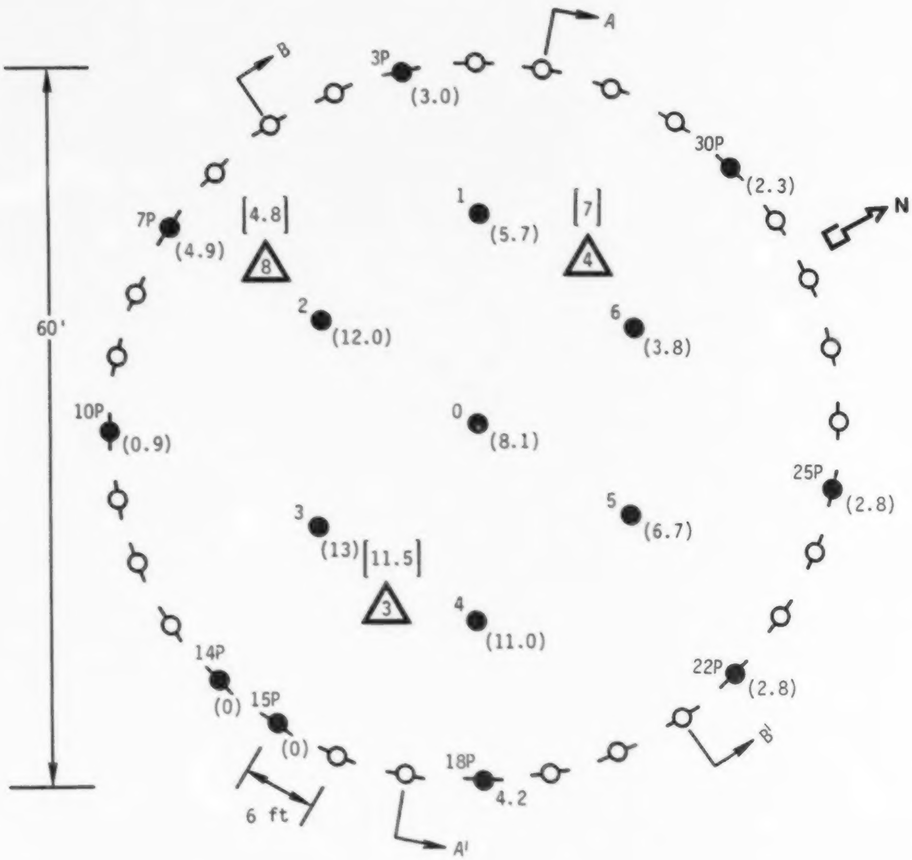
A total of approximately 2000 ft^3 of bentonite slurry was injected during the block lift operation. A daily tabulation of slurry injected during the lift operation was maintained by counting the number of 1-1/2 yd^3 batches of slurry mixed and verifying this count with a daily bag count of the bentonite used. A comparison of volume of slurry pumped with volume of block displaced is presented graphically in Figure 31. This figure indicates that the volume of slurry pumped initially exceeded the volume of block displaced, but that a consistent correlation was achieved at steady state. A detailed discussion of slurry flow and property monitoring is presented in subsection 6.3.

Data from surface topographic surveys and from accumulated daily lift records were combined to give the two profiles of the final block position shown in Figure 32. In total, the block was displaced upward in excess of 12 in. at its highest point and tilted approximately 1 degree from horizontal. A crescent shaped portion of the block outside of injection hole No. 3 was sheared free of the lifting block and did not move


3P
N
30P
7P
1
2
6
60'
0
10P
25P
3
5
4
14P
22P
15P
18P

P - DENOTES PERIMETER LOCATION
1 INCH = APPROXIMATELY 10 FEET

Figure 29. Whitehouse site map showing survey mark locations.



A
B
3P
(3.0)
30P
(2.3)
N
60'
7P
(4.9)
[4.8]
8
1
(5.7)
[7]
4
2
(12.0)
6
(3.8)
10P
(0.9)
0
(8.1)
25P
(2.8)
5
(6.7)
3
(13)
[11.5]
3
4
(11.0)
14P
(0)
15P
(0)
22P
(2.8)
B'
18P
4.2
6 ft
A'

LEGEND

BLOCK LIFT MEASUREMENT	7P ← NEAREST HOLE ("P" DENOTES PERIMETER) ● (4.9) ← ACCUMULATED LIFT (INCHES)
SEAL THICKNESS MEASUREMENT	[11.5] ← THICKNESS OF SLURRY (INCHES) △3 ← HOLE LOCATION OF BOTTOM SLURRY SAMPLE

NOTE: SECTIONS A-A' AND B-B' ARE SHOWN ON FIGURE 32

Figure 30. Recorded block lift and verified seal thickness.

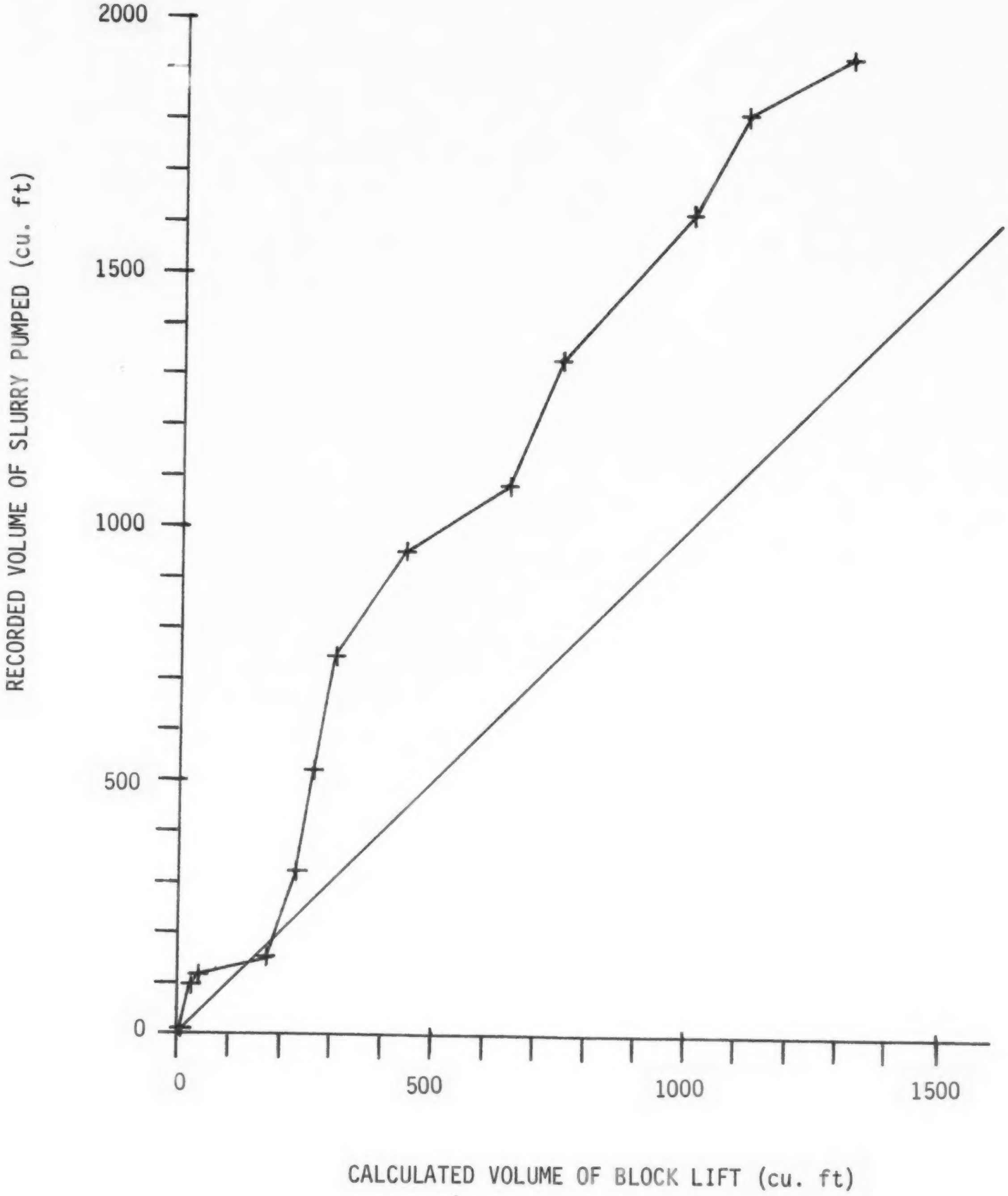
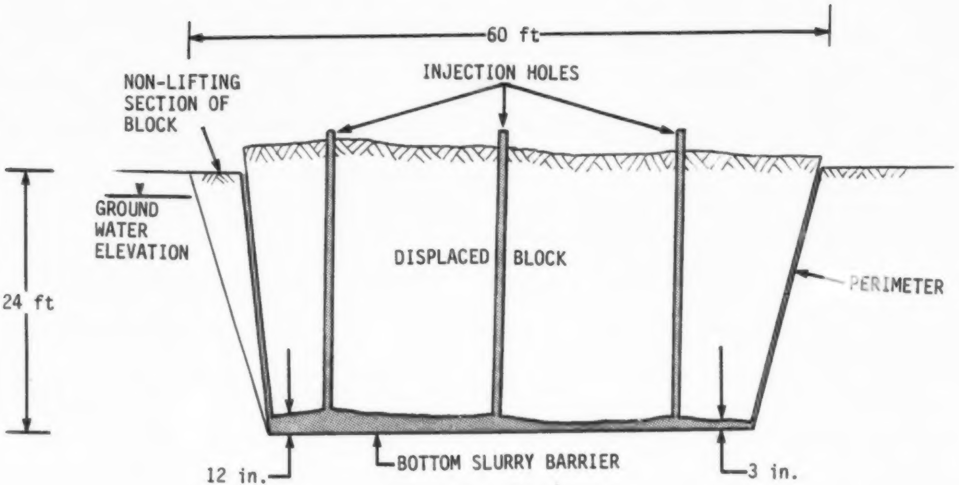
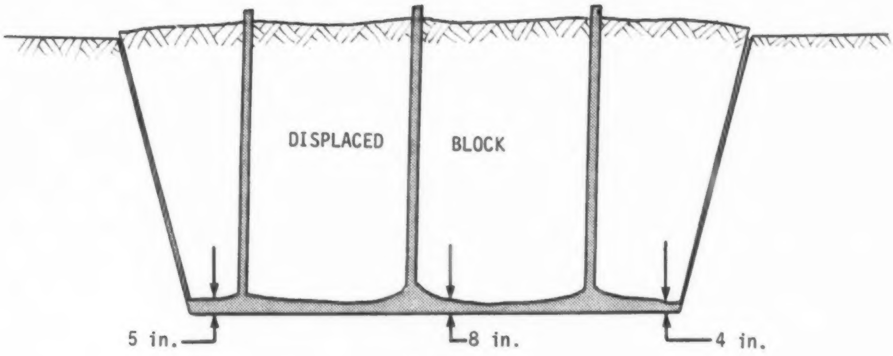


Figure 31. Comparison of slurry volume pumped to volume displaced during block lift.


60 ft
INJECTION HOLES
NON-LIFTING SECTION OF BLOCK
GROUND WATER ELEVATION
24 ft
DISPLACED BLOCK
PERIMETER
12 in.
BOTTOM SLURRY BARRIER
3 in.

SECTION A-A'


DISPLACED
BLOCK
5 in.
8 in.
4 in.

SECTION B-B'

Figure 32. Final block displacement.

appreciably. The entire remaining portion of the perimeter lagged behind the inner portion of the block, lifting only 3 to 6 in. A detailed discussion of the site survey is given in subsection 6.4.

The crescent shaped shear zone, tilting of the block and perimeter displacement lag were all attributed to an incomplete fracturing and freeing of the block around the perimeter. Following completion of the block lifting operation, 5 to 9 ft deep trenches were excavated through the perimeter and shear zone to determine causes of resistance to perimeter displacement. The trenching operation is described in subsection 6.5.

Tap roots as large as 24 in. in diameter were found at approximate 6 ft intervals extending from roughly 5 ft below the ground surface to the upper boundary of the hardpan layer. In addition, perimeter fractures filled with gelled slurry extended down only a few feet before becoming indistinguishable hairline fractures.

Thin walled tube soil samples were taken 4 weeks after stopping slurry pumping to determine the integrity of the bottom seal. Obtaining undisturbed soil samples of the soft slurry material bounded by hardpan on top and unconsolidated sand beneath was a difficult task. In eight attempts, three acceptable samples were obtained at the locations shown in Figure 30. A detailed discussion of the bottom barrier sampling procedures and results is presented in subsection 6.6.

6.2 BLOCK LIFT MONITORING

During the bottom fracturing and block lifting operation a precision surveyor's level was used with the following procedure to measure vertical elevations at various survey marks. The instrument and tripod were set and leveled for the day at the instrumentation station. The level was checked and calibrated against three independent fixed references. This assured that data could be correlated day to day and served to check the proper set up and working order of the level. The instrument height was checked at the beginning and end of each day. Instrument height was recorded in the field notes to the nearest 1/32 in. This measurement is referred to in the notes as the day's reference. Steel posts were used as survey marks, and survey mark locations were referenced to the nearest perimeter or injection well point. The survey mark locations and elevations are shown on Figures 29 and 30. Survey mark lift elevations were measured to the nearest 1/16 in.

Measurements were typically taken at the beginning and end of each day. This established overnight settlement and consolidation of the slurry, and total vertical displacements of the day. During the day, intermediate readings were taken to monitor areas of special interest or to establish control points during displacement. For example, the results of a set of readings taken across the block to establish differential lift, would directly influence the slurry injection pattern. Monitoring the rise and fall of a series of points during and after periods of injection would provide evidence of the rate of mud redistribution across the block, and the ability to establish differential pressure gradients across the block bottom.

The overall volume of block lift, as measured from the surface displacements, has been plotted against the volume of mud injected into the bottom seal. This plot is shown in Figure 31. The graph can be considered in two regimes - an initial "transient" response followed by a "steady state" response. In the "transient" region, the volume of mud pumped exceeds the volume of lift by a factor of two. This behavior can be attributed to compaction of the soil, initial leakoff prior to filter cake formation, and the possibility of extending fractures beyond the perimeter. Although some slurry leaked out through perimeter holes, this material was captured and repumped. The repumped material is not included in determining the volume of slurry pumped as identified in Figure 31. In the "steady state" regime, the volume of mud injected is equal to the volume of lift, as one would expect. The steady state region constitutes the bulk of the curve, and would most likely continue with continued pumping.

6.3 SURVEY OF SITE

A surface mapping of the site was constructed after block lifting was completed. Twenty-four survey marks were set, on and off the block. There were three fixed reference points for establishing a datum: a set of north-south, east-west survey marks just off the perimeter of the block; nine perimeter or near perimeter survey marks; and eight centrally located survey marks. In addition to these points, the seven central injection well heads were also located and used as supplementary and long-term survey marks.

The surface mapping of the site was conducted in three phases. The final result of the mapping is shown in Figure 33. The first phase produced a map that located the block relative to the surrounding area. The second phase establishes the true ground elevations for all survey marks relative to the local test site datum. This information was critical when a stake had to be moved as was required for survey mark No. 3 which was disturbed by the formation of the crack shown on Figure 33. This survey information was the source of data for constructing the final topographic map which was prepared during the third phase. This effort included location of the map contour lines, fault escarpments, and surface cracking. Figure 33 shows the most pronounced feature

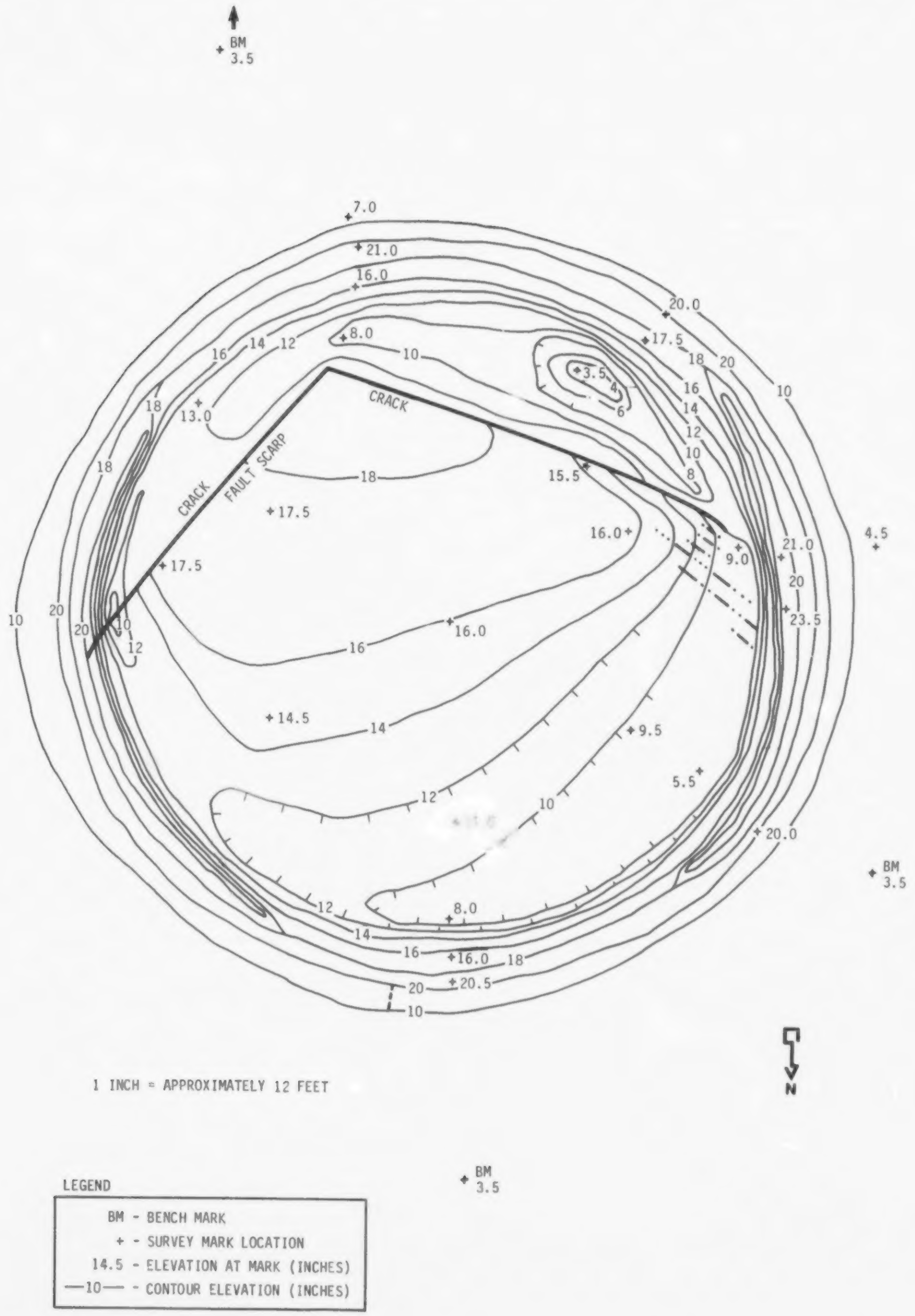

BM 3.5
7.0
21.0
16.0
20.0
8.0
10
17.5
18
20
3.5
4
6
16
14
12
13.0
CRACK
FAULT SCARP
15.5
16.0
9.0
21.0
23.5
4.5
17.5
16.0
14.5
9.5
5.5
20.0
8.0
16.0
20.5
1 INCH = APPROXIMATELY 12 FEET
N
LEGEND
BM - BENCH MARK
+ - SURVEY MARK LOCATION
14.5 - ELEVATION AT MARK (INCHES)
—10— - CONTOUR ELEVATION (INCHES)

Figure 33. Topographic survey map of the Whitehouse test site.

of the site, the major fault escarpment and associated minor cracking that bisects the site. The maximum vertical displacement along this fault occurs at the point intersection of the two legs of the fault between wells No. 3 and No. 4. These two legs intersect at a 120 degree angle. The maximum vertical displacement at the escarpment is 6 in. while the total maximum displacement is 11-1/2 in.

6.4 MUD MATERIAL PROPERTY TESTS

Five different muds were used during the Block Displacement field operation.

In the block perimeter holes two different muds were used. Downhole a high density barite mud was used, with very low gel strength and a specific gravity greater than 2.0. Above this first mud a second surcharge mud was used to contain the perimeter blasting. This second mud was very sandy, with high gel strength and a specific gravity greater than 2.0.

For the block fracturing and displacement operation, three different slurry muds were used. The first was a low gel strength cutting mud containing 1 to 2 percent bentonite. The cutting mud was used exclusively in the bottom notching operation. The second slurry mud used under the block was the fracture propagating mud, containing 5 to 10 percent bentonite. The cutting and fracturing muds accounted for less than 2 percent of the total mud used at the site. The major portion of the Block Displacement was due to the injection of the lifting mud. This mud contained also 5 to 10 percent bentonite, but was greatly bulked by the addition of local surface sands. The specific gravity of this mud was 1.9.

Standard A.P.I. 30 min filter press tests were run during the course of the lift operation to monitor the quality of the injection mud. The results are listed below:

Sample	30 minute filtrate ml
T.B.1	14.9
J.C.2	15.0
J.C.3	12.9
J.C.4	11.6
T.B.5	12.0
J.C.6	9.0
J.C.7	10.9

This filter press test field data can be used to estimate slurry permeability by calculation as follows:

$$P = \frac{VT}{ATH} \qquad (13)$$

Where V = volume of filtrate (ml)

A = cross sectional area of filter press (130 cm^2)

t = estimated thickness of filter cake or active slurry (cm)

h = pressure head across slurry (~6100 cm)

T = time (30 min)

Based on the above sample reading with an estimated filter cake thickness of 1.3 cm the average permeability of the lift mud was 1.0×10^{-8} cm/sec.

6.5 TRENCH MAPPING

At the conclusion of the Block Displacement test and surficial site mapping, three exploration trenches were dug through the block perimeter. This allowed a close inspection of near surface geology. This also allowed for mapping the depth of any features associated with or affecting the Block Displacement operation berm blast holes and fractures, tree roots, unusual sand or silt layering, etc. Figure 34 shows the position and geometry of the three exploratory trenches. This figure also shows the position and approximate diameter of the numerous tree stumps which were found 3 to 5 ft below the existing ground surface. The trenches ranged in depth from 5 to 9 ft, and were dug primarily through the berm areas.

One of the most noticeable finds during trenching was a large number of cypress tree stumps and tap roots. These ranged from 2 to 24 in. diameter, and were spaced 4 to 6 ft on center. The primary difficulty that these roots and stumps might have presented would have been the formation of uncontrolled mud flow paths from the perimeter of the block to the surface.

The trenching operation also allowed close inspection of the perimeter blast holes. The fracturing pattern at each blast hole was traceable by following the bentonite filled sheet fractures radially outward from the center of the blast holes. These sheet structures were traceable to thicknesses of less than 1/4 in. These fractures extended laterally 2 to 4 ft, and extended below the depth of the excavations. In general these fractures were non-planar in geometry.

The surface and near surface sedimentary sand deposits were mapped at this time. Following are descriptions of the various units starting at the existing ground surface.

The top sedimentary sand is a slightly silty to silty, fine to very fine grain quartz sand, 3 to 5 ft thick. It contains less than 5 percent organics in the bulk of the unit, but the

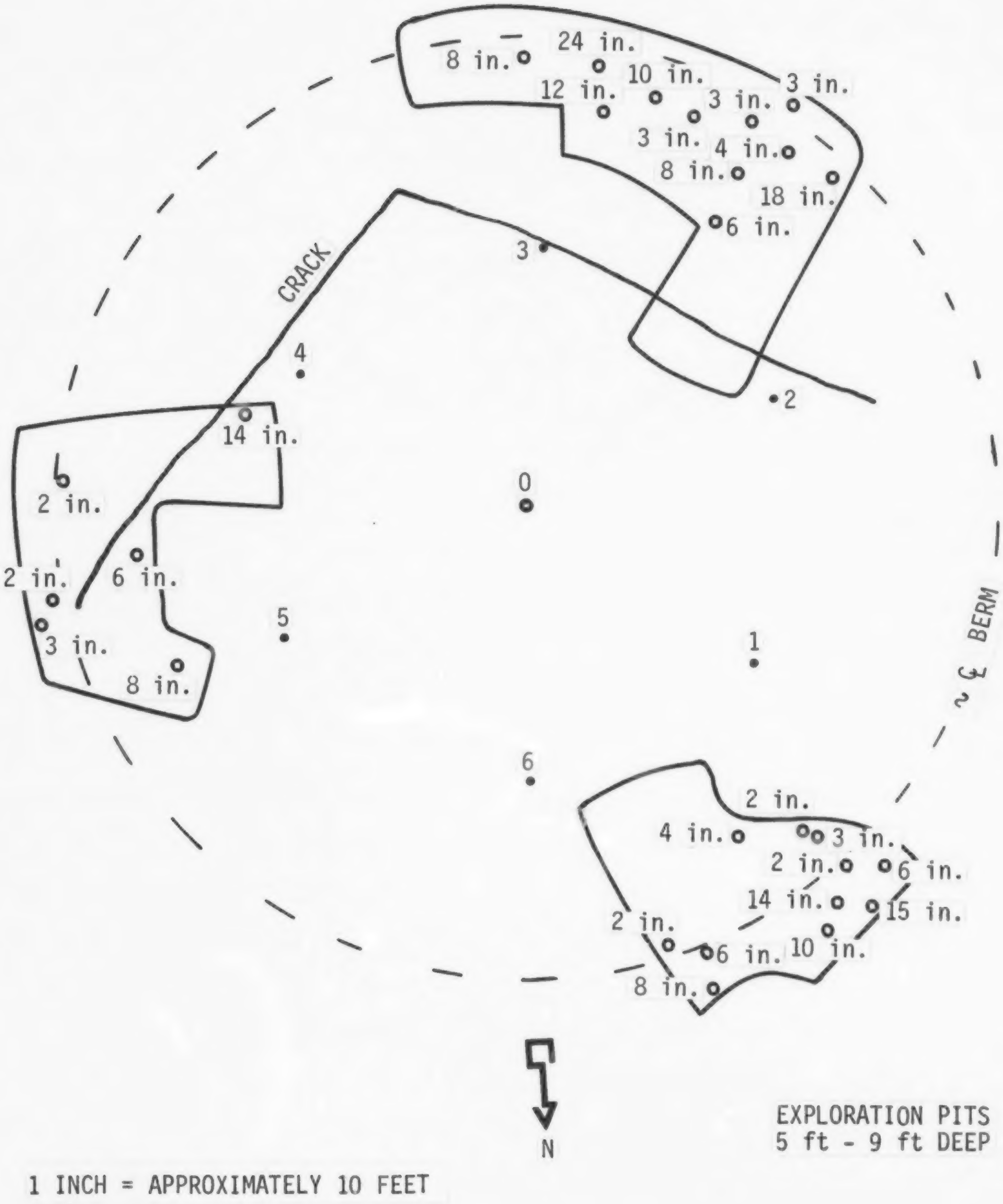

8 in.
24 in.
10 in.
12 in.
3 in.
3 in.
3 in.
4 in.
8 in.
18 in.
6 in.
3
CRACK
4
2
14 in.
0
2 in.
2 in.
6 in.
3 in.
8 in.
5
1
BERM
6
2 in.
4 in.
3 in.
2 in.
6 in.
14 in.
15 in.
2 in.
6 in.
10 in.
8 in.
N
EXPLORATION PITS
5 ft - 9 ft DEEP
1 INCH = APPROXIMATELY 10 FEET

Figure 34. Exploration trenches showing the position and size of tree stumps.

top 1 ft contains numerous grass and plant roots. In situ, the sand is a mottled tan to greyish tan in color and is mostly consolidated. The surface sands appear black when wet but light grey when dry. This unit provided the sand taken from the site's borrow pits and used to bulk the lifting mud. This sand changed the color of the displacement mud to black.

Below the top unit is a perched aquifer in a 1/2 to 2 in. thick layer of medium fine grain quartz sand. Almost all silts and organics have been leached from this layer, and it appears very light grey to white in color. Water did not flow freely but rather wept from this unit.

The third unit down is a silty, fine to very fine, quartz sand. It is dark grey to brownish grey in color, containing a higher organic percentage than the first unit. The unit was mostly consolidated and varied in thickness from 4 ft thick in Pit No. 1 to 1 ft thick in Pit No. 3. In general, this unit became blacker and siltier with depth. In Pit No. 3, the 1 ft thick section most closely matches the bottom of the unit in Pit No. 1.

Below the third unit is a second perched water bearing sand layer. This layer is a 4 to 8 in. thick quartz sand. The layer continually collapsed as it was excavated, and the water inflow rate was sufficiently high to prevent effective trench exploration below it.

The last visible unit was a very dark, near black, quartz sand. This layer appeared to be saturated. Based on penetration tests, the sand was loosely consolidated at least 2 ft below the excavation depth, but it was felt that this unit represented the weathered top of the hard pan layer.

The major surficial feature of the site was the fault escarpment transecting the uplifted block. This crack was trenched across in two places. Although vertical offset was over 6 in. at the ground surface, ground movement was only traceable to depths of 3 to 4 ft. This is due to the fact that the loosely consolidated surface sands did not preserve any displacement features.

It is important to the theories and methodologies of Block Displacement, to understand the mechanisms by which this fault escarpment evolved and developed. A simple shear failure of the sediments due to high lifting slurry pressures does not seem to be the best model. This is because the sediments would not shear through at a relatively undisturbed section of ground, and yet fail to shear at the nearby prefractured perimeter.

A second theory is tensile failure of the block through uplift and bulging with subsequent down dropped block faulting.

This at first seems in agreement with the geometry of the crack and surrounding topography. However, a closer examination of the total block geometry reveals that this mode of failure alone does not allow for the magnitude of displacement visible at the surface.

For a theory to be viable it must take into account all the features expressed by the total fault system and movements of the block. The following series of events is a hypothesis which explains all observed features.

As the block was initially displaced it bulged or lifted to a greater degree at the center than at the edges. This is attributed to excessive perimeter shear resistance, due either to geometric interlocking or insufficient perimeter fracturing. This bulging then caused a surficial tension crack to appear. As the bulging progressed the tension crack extended downward as strains overcame the plastic limits of the sediments. Eventually this crack weakened the hard pan layer to such an extent, that, the hard pan failed in shear due to the differential loading at the bottom of the block. After this, the shear failure was the major driving force to the large vertical displacements visible at the surface. This theory seems best to fit the evidence; that is, the shape of the fault, the displacement of the fault, the amount of vertical uplift before the crack appeared, and the differential lift as the escarpment formed.

6.6 SHELBY TUBE SAMPLING

The final verification testing at the site by FMI was actual core sampling of the bentonite layer. This also proved to be the most difficult verification task. In general, the problem centered around how to recover a very soft plastic layer sandwich between two very compact layers. Atop the bentonite layer was manganese cemented hard pan and beneath, a very well compacted brown sand. A second significant problem was location of the slurry barrier horizon.

Because of the importance of barrier verification, FMI sought advisory opinions from both a local Florida geotechnical company (Ardaman and Associates) and from a Boston based geotechnical consultant (Haley and Aldrich). Both firms recommended the use of a fixed piston pushed, thin walled tube sampling technique. It was felt by both groups that a thick wall impact driven sampler (e.g., split spoon) would not recover a representative slurry sample. It was additionally felt that the geometry of these type spoons and the impact required for their use would push the mud aside and disturb any recovered sample. The decision was made, therefore, to carry out initial core sampling using a 3 in. by 30 in. shelby tube.

A major problem was locating the sampling depth for core work. The first attempted solution was to auger a hole adjacent to the desired core location to log the strata. Then, based on this information, drill a new hole 12 to 18 in. away from the first core at a predetermined depth. This technique met with limited success because it did not locate with sufficient accuracy the depth of the slurry layer. The technique which was used with some success relied mostly on the skill and feel of the driller. A flat bottom cruciform drill bit was used to drill into the hard pan. Because of the tendency of the hard pan to soften at the top and bottom, the driller would try to feel the bottom of the hard pan layer. The basic technique would be to drill in 4 to 6 in. drives, stop drilling, then attempt to press the drill bit down. This created no movement in the hard pan. However, as the unit softened, a slight drill bit settlement was perceivable. This required a bit of precision and a bit of luck. This technique was limited to sampling mud layers greater than 3 or 4 in. in thickness due to limited resolution of drilling in 6 in. drives.

The shelby tube was able to penetrate only the last 3 to 5 in. of the hard pan layer and the first 4 to 6 in. of the very well compacted sand layer beneath. A maximum allowable push of 26 in. was established to avoid possible compaction of the sample.

Three excellent core recoveries were obtained. These were in test wells numbered 3, 4 and 8. Appendix E includes detailed logs of these test borings.

Test Core Hole No. 3

Test core hole No. 3 was located between injection wells 3 and 4. The sampling depth was between 19.4 and 21.4 ft. The 3 in. diameter by 30 in. shelby tube was pushed a total of 24-1/2 in. The first 20 in. was referred to as soft push while the last 4-1/2 in. was referred to as firm push. A total of 19 in. of sample was recovered. There was 1 in. of sample loss at the bottom of the tube. After splitting the sample in the field, a 3-1/2 in. layer of hard pan, a 11-1/2 in. layer of bentonite slurry and a 4 in. layer of well compacted brown sand was observed. It is believed that the majority of the 4-1/2 in. of unaccounted sample loss occurred in the plastic slurry region. The mud layer at test well No. 3 is therefore a minimum of 11-1/2 in. thick with a possible maximum thickness of 16 in.

Among the major features identified in this sample were the very high contrast in texture and color between the naturally occurring sediments and the slurry. Texture of the hard pan and sand were friable while the mud slurry was extremely plastic as can be seen in Figure 35. The hard pan was very dark brown to dark reddish brown, the sand a medium brown to

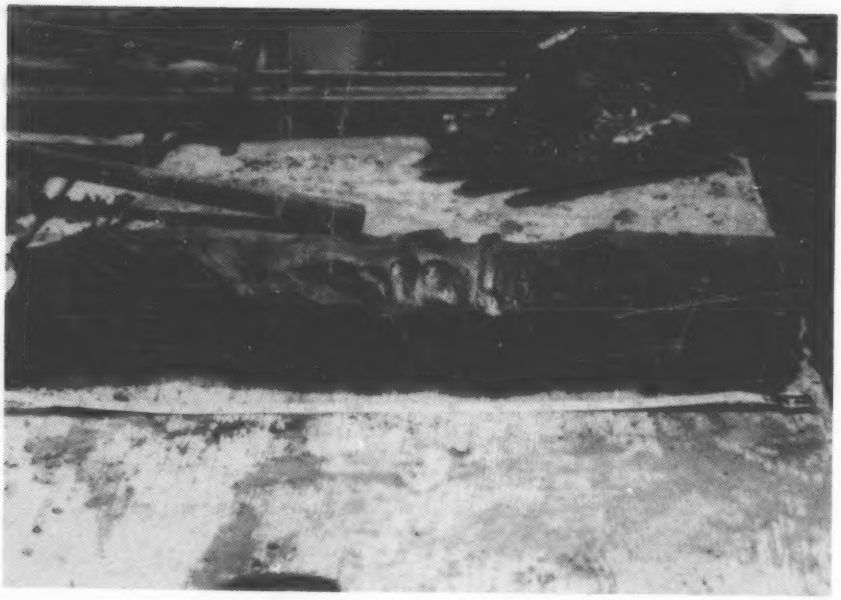


Figure 35. Core sample from hole No. 3 showing contrast between hard pan, sand and mud slurry.

ochre brown while the consolidated slurry was nearly black. The slurry showed the coloration of the wet silty surface sands used to bulk the slurry.

Another distinctive feature was color contrast between the fracturing mud and the lifting mud. The lifting slurry was almost black in color while the fracturing mud was a light grey. Also, the fracturing mud contained no sand and had a buttery texture. The fracturing mud showed up in two marbled zones at the interface of the mud and hard pan on top and the mud and bottom sand. The fracturing mud extended in marbled veinlets both into the lifting mud and into the sand and hard pan. Sample No. 1 showed that traces of bentonite fracturing mud extended into the brown sand layer at least 10 in. deep, indicating that multiple fractures occurred before a major separation plane was fully developed.

Test Core Hole No. 4

The core sample from test well No. 4 was the second acceptable core recovered. Test well No. 4 was located between injection well point 1 and 6 and the core sampling depth was 23.5 ft to 24.75 ft. Total core push was 16 in. and the total sample recovered was 16 in. (100 percent recovery). The coring technique was the same as that used to sample core hole No. 3.

The shelby core shown in Figure 36 from top to bottom contained 2-1/2 in. of the bottom of the hard pan layer consisting of a partially cemented medium fine grain dark brown sand; 7 in. of lifting mud showing trace fracturing mud marbled at both upper and lower contacts; and 6-1/2 in. of very hard brown sand of the under layer unit. Three features are noteworthy in this core.

First, 7 in. of mud was recovered. This is a larger thickness of consolidated slurry than one would expect from the surface displacements. Stake No. 1 at well point 1 was displaced 6 in. while stake No. 6 was displaced only 3-5/8 in. The core sample was taken approximately halfway between these two points.

A second feature is that the slurry was more consolidated than that in sample core No. 3, indicating either thicker injection slurry or higher local porosity of the surrounding units.

A third feature was the underlying brown sand, more compacted than that found in sample No. 3. Also it was marbled, with fracturing slurry throughout. In addition, the differences between the overlaying hard pan and underlying sand was much less conspicuous in this sample. This indicates that the hard pan contact was not well defined across the block, but that the two units graded into each other in some areas.

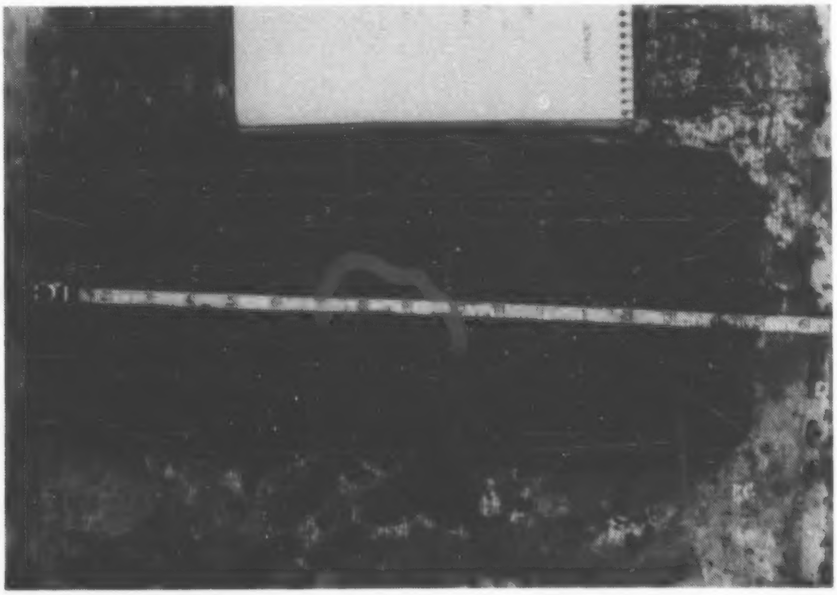


Figure 36. Test core from hole No. 4

Test Core Hole No. 8

Test core hole No. 8 was located between injection wells 1 and 2, approximately 8 ft from well No. 2 and 23 ft from the center of the block. This should locate it within 3 ft of the bottom outside edge of the block. The sampling depth was 22 ft - 8 in. to 24 ft - 7 in. Of a total push of 23 in., a core length of 17-1/2 in. was recovered. This core contained 2-1/2 in. of hard pan at the top, 4-3/4 in. lifting mud in the middle and 9 in. of dark brown sand on the bottom as indicated in Figure 37.

It is very difficult to assess the recovery of this sample. This is due to the fact that on the first attempted coring, no core was recovered. The core was repushed and a reasonable but slightly disturbed sample was recovered. A trace of the first push can be seen in the photo documentation of the core. What can be said is at a minimum 4-3/4 in. of bentonite slurry seal is in place at approximately 22 ft - 10 in. to 23 ft - 3 in. below ground surface elevation.

The fracture mud was also visible in this core sample at the mud soil interface but was not as extensively marbled as in the two samples discussed previously.

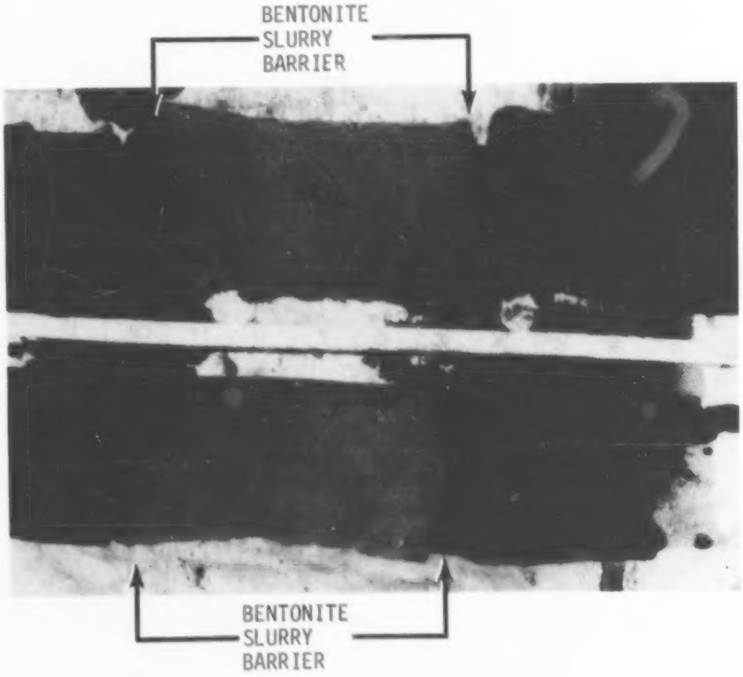


Figure 37. Test core from hole No. 8.

SECTION 7

CONSTRUCTION SPECIFICATIONS

This section is a general guide to the engineer planning a Block Displacement project. Block Displacement design and construction procedures are related closely to slurry trench construction techniques, with a few notable differences.

Block Displacement barrier construction occurs remotely through a series of injection wells. Bentonite slurries must be pumped under pressure into these wells - the first difference with slurry trench practice. A second difference is the relatively low slurry volumes and flow rates required for Block Displacement. Finally, the Block Displacement technique employs a range of slurries throughout the process, each designed to accomplish a specific task.

The following subsections identify:

- Required preconstruction site information
- Potential for integration with other remedial measures
- Construction material and equipment specifications
- Barrier performance verification and monitoring techniques.

7.1 REQUIRED PRECONSTRUCTION SITE INFORMATION

There are two categories of information required in the site investigation: the site information which determines the applicability of the Block Displacement technique, and that which establishes the physical constraints affecting constructions.

Applicability of the Block Displacement Technique

The applicability of the Block Displacement technique to a site is based on a detailed surface and subsurface investigation. This investigation should include the following:

- Geologic and topographic survey maps
- Hydrologic reports

- Soil surveys

- Surface excavations and test borings, perhaps including: continuous core sampling; standard penetration resistance measurements; mapping of the subsurface stratigraphy including thickness, uniformity, slope and dip, and lithology of all units, including permeability and porosity

- Groundwater survey, including water table level and direction and rate of groundwater flow

- Chemical analysis of contaminated and uncontaminated ground waters

- Geophysical surveys, which can be useful in determining the extent of the contaminated plume, the uniformity of the near surface geology, and the presence of small subsurface irregularities such as buried foundations, pipes, small land fills, etc.

The site investigation should also determine the potential effects of the contaminated ground water and ground chemistry on the Block Displacement slurries. Bentonite slurries can be designed to maintain their properties in the presence of various chemicals. Slurry properties such as filter cake buildup, shear strength, gel strength, viscosity, and pumpability are very critical and must be predictable during the construction of the Block Displacement barrier. The overall permeability of the barrier is a longer term consideration. Reactions with unexpected chemicals might reduce the overall effectiveness of the barrier. Design considerations should include the possible degradation of barrier performance based on the life expectancy of the barrier.

Construction Constraints

There are many physical constraints that can affect the Block Displacement construction process. The initial site survey should include a review of these constraints. This review should, as a minimum, answer the following questions:

- Topography - Is there sufficient drainage? Is grading required?

- Vegetation - Will the area require clearing for survey work, or moving and placing equipment? Will vegetation be needed to prevent local erosion?

- Water - Is water for the slurry available on site in the quantity and quality desired, or will water have to be trucked?

- Borrow Material - Are suitable sands, clays, and soils available locally to make soil/bentonite slurries? How much is available? How far away? In what condition is it?

- Right of Ways - Will the power lines, gas, water, sewer, roads, etc., interfere with construction?

- Space Constraints - Is there access to the site? Is room available to stage equipment? Are there buildings or property lines to work around? What about material storage?

- Personnel Safety - Will protective clothing be needed? What about respirators, decontamination equipment, safety monitoring instruments?

7.2 INTEGRATION WITH OTHER REMEDIAL MEASURES

The Block Displacement technique is one tool that can be used in conjunction with other remedial measures for isolating and perhaps cleaning up a hazardous waste site. Complementary remedial measures include:

- Slurry walls
- Impermeable caps
- Groundwater flushing
- Partial excavation of waste
- Excavation and encapsulation.

The interaction between remedial measures must be considered at the design stage.

Block Displacement offers potential as a stand alone control or integrated with one or more complementary measures. Where and how it can be employed economically, as well as the extent to which it should be utilized, are design decisions based on engineering judgement. Factors which influence the applicability and the economics for a specific application include:

- Barrier materials and barrier thickness must be chosen based on the life expectancy of the barrier and the design permeability

- Barrier materials must be compatible with the waste chemicals and, where applicable, those intended for chemical flushing

- The barrier placement should not have deleterious effects on other remedial actions such as existing slurry walls or caps. If subsequent flushing by groundwater pumping is envisioned, the permeability of the contaminated soil should not be reduced

- Proper scheduling of complementary measures can dramatically affect both the economics and the effectiveness of the overall effort.

7.3 CONSTRUCTION MATERIALS AND EQUIPMENT SPECIFICATIONS

The materials used in Block Displacement are familiar to the construction industry as they are similar to those employed in slurry trenching. The equipment is much less familiar.

The Block Displacement technique described in Section 1 of this report reflects process changes and refinements based on the experience gained in conducting the demonstration described in Section 5. Most significantly, the drill, notch and blast perimeter construction technique described in Section 5 was found unsatisfactory. Consequently, for the purpose of construction specifications, traditional slurry wall construction will be recommended for the block perimeter.

Construction materials for Block Displacement include:

- High gel bentonite clay
- Water
- Bulky solids - sand, silt, clay.

For some specific applications, a material such as barite may be added to the slurry to increase its density.

Block Displacement is accomplished in four distinct steps or stages:

- Drilling and setting cased well points

- Notching the soil at the base of these injection wells

- Hydraulic fracturing and coalescing of the basal fractures

- Vertical displacement of the block.

At each stage, specific equipment and control measures are essential. Table 8 summarizes the equipment required and the nature and accuracy of the controls recommended at each stage of the process.

TABLE 8. BLOCK DISPLACEMENT EQUIPMENT REQUIREMENTS

Task	Equipment	Measurements, controls, accuracy
Stage One: Drilling and setting cased well points		
Lay out well pattern	Surveying instruments: engineer's level, bench marks, tape, rod	Wells to be located 0.5 ft vertically 1.0 ft horizontally
Drill and set cased well points or Hammer Driven well points	Truck-mounted rotary drill rig Small pile driver, and well point driving shoe	Wells to be located 0.5 ft vertically 1.0 ft horizontally
Set lift control survey marks	[illegible]ing instruments	Survey mark to be located ±0.01 ft vertically ±0.2 ft horizontally
Stage Two: Notching the wells		
Prepare 2% bentonite notching slurry	Soil/bentonite (S-B) batch plant	Standard plant accuracy and control
Notching	Notching tool 200 psi jet pump 50 cfm x 100 psi air compressor	Air pressure Downhole slurry level Slurry return back-pressure
	Two fluid rotary swivel well heads Settling tanks Miscellaneous equipment, air hoses, slurry hoses, valves, etc.	Cutting volume
Stage Three: Hydraulic fracturing		
Prepare 2 to 6% bentonite fracturing fluid	S-B Batch Plant	Standard plant accuracy and control
Fracture and monitor lift	Slurry pump: 20 yd^3/hr at 100 psi Slurry lines, 3 to [illegible] in. "concrete type" slick lines Manifolds and valves Well head valve, for removing notching tool (optional) Surveying instruments	Slurry flow rate Slurry volume Slurry pressure Block lift ± 0.01 ft vertically
Stage Four: Block Displacement		
Lift block	S-B Batch Plant S-B slurry pump: 20 yd^3/hr at 100 psi	Standard plant accuracy and controls
Monitor block lift	Slurry lines Manifolds and valves Surveying instruments	Slurry flow rate Slurry volume Slurry pressure Block lift ± 0.01 ft vertically

The area and the depth of the block to be isolated are determined based on the initial site survey. The area depends on the extent of the contamination. The bottom barrier is generally placed below the seriously contaminated zone in the first soil strata judged favorable to the Block Displacement process.

Drilling and notching should proceed as described in Section 5 of this report. Fracturing should follow notching immediately to prevent the collapse of the notch. One suggested approach involves pumping fracturing fluid through the notching tool, thereby minimizing the time between notching and fracturing. An alternative to pumping fracture fluid through the notching tool is to design a well head cap valve that allows the removal of the notching tool while continuously pumping pressurized slurry into the borehole. This has the advantage of allowing notching and fracturing to be performed concurrently at different holes.

The most critical piece of equipment in all these tasks is the soil/bentonite batch plant. The batch plant must be constructed to meet all Block Displacement slurry requirements. Table 9 lists the basic equipment needed for this plant.

TABLE 9. SOIL/BENTONITE BATCH PLANT EQUIPMENT

S-B quality control equipment:

- Marsh funnel
- Fann filter press (or equivalent)
- Shearometer
- Unit weight mud balance
- pH tester
- QC field notebook

S-B mixing equipment:

- Bentonite, soil, sand storage area
- Soil and sand screening facility
- Earth moving equipment (front end loader)
- Bentonite slurry jet pump mixer (20 yd^3/hr)
- 5 yd^3 bentonite slurry hydration tank
- 5 yd^3 S-B batch mixers (2 required)
- Manifolds and valves (assorted)

7.4 BARRIER VERIFICATION AND PERFORMANCE MONITORING

The development of the barrier must be monitored during the construction phase, and its performance verified throughout its intended life. Different monitoring techniques are employed during the construction phase and during the extended performance monitoring. In the following we detail the recommended techniques for monitoring and verifying the Block Displacement barrier and for maintaining barrier effectiveness over an extended life.

7.4.1 Construction Monitoring

During the construction phase of Block Displacement, the following must be monitored:

- Slurry quality
- Block lift
- Slurry pumping pressure
- Slurry volume.

7.4.1.1 Slurry Quality--

Subsection 7.3 described the equipment needed to control the quality of the slurry used. The use of A.P.I. test equipment is well documented and will not be discussed further. The field engineer should be responsible for the following slurry quality checks:

- Bentonite source, specifications, storage
- Mix water chemistry and supply
- Slurry weight, viscosity, shear strength, gel strength, pH
- Slurry field additives
- Slurry permeability and filter cake development
- Soil quality, source, storage
- Quality of bentonite slurry mixing
- Quality of soil/bentonite slurry mixing.

7.4.1.2 Block Lift--

The block lift should be measured to ±0.01 ft during the construction phase. In addition, the ground swell or displaced volume should be calculated. There should be a direct correlation of slurry volume pumped to block volume displaced.

7.4.1.3 Slurry Pumping Pressures--

Slurry pressures provide an indication of the fracture thickness and interconnection between wells as discussed in Section 4.2. This information is also used in controlling the viscosity or slump of the soil/bentonite slurry. During Block Displacement, progressively thicker slurries are used. Typically, the more viscous the slurry, the higher the pumping pressure. The maximum allowable well head pressure is usually the control factor on the slurry design.

7.4.1.4 Slurry Volume--

Slurry volume pumped data is used for correlation with the volume of block displaced. It permits early identification of major leakage into underground cavities or even to remote surface locations. Recording the number and volume of the batches pumped should provide sufficient accuracy.

7.4.2 Extended Barrier Performance Monitoring

The barrier performance must be monitored both immediately after construction and throughout its operating life. The quality of the barrier as constructed can be verified by a draw down test and by geophysical surveying. Long term barrier performance is best determined through a series of monitoring wells, and long term water quality monitoring.

7.4.2.1 Draw Down Test--

A draw down test is the only procedure available for testing the overall permeability of a displaced block. A hydraulic gradient is established between the block and the surrounding land. This is best accomplished by pumping water out of the block to ensure minimum loss of contaminated ground water. The subsequent change in water level within the block is then a direct measure of the influx of water from the surrounding soil. Knowing the area of the barrier and the hydraulic gradient, the difference between the depth of the water level in the block to the height of the water table outside the block, an overall permeability can be established. There are two important considerations in performing a draw down test:

- Reversals of the hydraulic gradient could disrupt the filter cake with a resulting negative effect on the seal

- In a harsh environment, the barrier performance is likely to degrade with time, requiring repeated tests.

7.4.2.2 Geophysical Techniques--

Geophysical surveys can be a powerful tool in the verification of the barrier. It is important that a baseline survey be performed before construction. Perhaps the best application of geophysical surveys would be the identification of thin areas or discontinuities in the barrier. The draw down test measures the overall permeability of the block. It does not distinguish, however, between a moderate leakage rate distributed over the entire barrier and a very low leak rate through most of the barrier combined with occasional "holes" with high local leakage rates. If holes exist, a geophysical survey could identify and locate areas to be patched.

7.4.2.3 Monitoring Wells--

Piezometers installed in monitoring wells will measure directly the ground water hydraulic gradient across the barrier. Water quality monitoring can also be performed as desired to determine levels of contamination both within and outside the barrier. Unexplainable increases in levels of water contamination outside the barrier probably indicate breaching. Monitoring wells are an excellent approach to long term monitoring because of their relatively low cost and flexibility of use.

7.4.2.4 Extended Block Survey--

Ground movements inside or outside the block during or after construction can indicate problems with the barrier. As with slurry wall construction, horizontal and vertical ground movements should be surveyed. The survey marks established during construction of the barrier make an excellent base survey. Some of the tools available for these types of surveys include:

- Optical survey
- Inclinometer
- Extensometers
- Piezometers
- Settlement gages.

7.4.3 Maintenance

Generally, very little maintenance should be required over the expected life of the barrier. The most likely cause of required maintenance would be to extend the service life of a barrier originally intended for short term use. The Block Displacement technique is maintainable and repairable. The basal fracture can be reactivated. Having once established a horizontal barrier, this barrier provides an ideal geology for constructing a second barrier.

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APPENDIX A

FIELD DATA CHRONOLOGY

Date	Hole No.	Notching tool	Notch size Volume cuttings	Notch size Caliper	Comments	Volume slurry	Type slurry	Hole No. connected to
6/1	2 N	Original one			Perimeter notch tool fabrication.			
6/2	3 N	Original one			Major effort - perimeter notching.			
6/3	4 N	Original one			Major effort - perimeter notching.			
6/4	5 N	Original one			Major effort - perimeter notching plus sonotube.			
6/5	6 N	Original one			Set 8 sonotubes.			
6/7					Set 20 sonotubes.			
6/8	0 N	Original one			Finish sonotubes and BLASTED.			
6/9					General preparation for fracturing.			
6/10	0 F	Original one			Leaked near casing after $\sim$0.3 yd^3 pumped. Sealed with $\sim$3 to 5 ft^3 sandy mud.	0.3 yd^3		
6/10	5 F	Original one			All holes resisting flow.			
6/11	5 N	Original one			Reundercut (N). Connected to perimeter.	0.5 yd^3	High spirt	

N = Notch, F = Fracture, VN = Vertical notch.

Date	Hole No.	Notching tool	Notch size Volume cuttings	Notch size Caliper	Comments	Volume Slurry	Type slurry	Hole No. connected to
6/12	6 N	Original one			Reundercut (N). Resealed with thicker mud.	0.5 yd^3	High spirt	
6/12	1 N	Original one			Leak at fracture 5 ft from casing. No perimeter connection.	0.8 yd^3	High spirt	
6/14					Grouted casings No. 1 and No. 6. Cemented collars No. 1, No. 5, and No. 6.			
6/15					Grouted casing No. 10.			
6/16	0 N	Original one		30 in. ±			Cutting fluid	
6/16	0 F	Original one			Leaks in sump wall and near hole No. 1.	0.3-0.5 yd^3		
6/22	3 N	Original one	0.6 ft^3					
6/23				Measured at eight radial points 3 → 12 in.	Verification of No. 3 depth and notch size/shape (morning).			

N = Notch, F = Fraction, VN = Vertical notch.

		Notch size						
Date	Hole No.	Notching tool	Volume cuttings	Caliper	Comments	Volume slurry	Type slurry	Hole No. connected to
6/23	3 N	"DD"	$\sim$1.2 ft^3		Undercut to full extension at seven places.			
6/23	3 F				Channel leak 18 in. from casing No. 3. 1 to 2 gal at surface. All casings at 15 psi. Center only holds 5 psi.	1.5 yd^3	5 to 10% bentonite	
6/24	3 F				Slight channel leak 18 in. from No. 3 casing. Pressured No. 2 and No. 4 to 15 psi.	0.2 yd^3	8% bentonite	
6/24	4 N	Original one	$\sim$1 ft^3		Notch with 2% mud.	0.4 yd^3	2% bentonite No CMC	
	4 F				Fracture with 6% mud. Connection to perimeter. Leak 6 in. from No. 20 sonotube.	1.4 yd^3	6% bentonite	20
	4 F					0.4 yd^3	Sandy mud	
	4 F				Filled and overflowed No. 20 sonotube.	0.1 yd^3	8% bentonite with CMC	20
	3 F				Pressured to 35 psi. Channel leak 18 in. from casing, again.	$\sim$0.1 yd^3	8% bentonite with CMC	
6/25	4 N	Original one			Notched for 5 min.		8% mud	
	4 F				Leaked quickly at No. 20.		8% mud	20
	3 N	Original one			Pressured to 30 to 40 psi. Reopened channel 18 in. from casing.		2% mud	

N = Notch, F = Fracture, VN = Vertical notch.

Date	Hole No.	Notching tool	Notch size Volume cuttings	Notch size Caliper	Comments	Volume slurry	Type slurry	Hole No. connected to
6/25	3				Pumped healing mud.	~0.1 yd^3	2% bentonite plus sand	
	3				Continued healing. Hole sealed.		8% bentonite plus sand	
	3 VN	Original one			Notched vertically ~6 in. down.			
	3 N	Original one	~1 ft^3		Horizontal notch for 15 min.			
	3 F				30 to 40 psi. Reopened channel 18 in. from casing.	0.03 yd^3		
6/26	3				Healing mud pumped 10 gal/5 lb grits 5 in., 3 to 4 in. oats. Pressured to 40 psi. No leaks.	0.1 yd^3	Oats and grits, mud	
6/26	3 VN	Original one			Erode out oats and grits.			
	3 N	Original one	~1 ft^3		Notched at 24 ft depth.		High spirt, 1 to 2% bentonite	
	3 F				Pressured to 45 psi. No breakdown or flow. Lowered tool to 25 ft.			
	3 N	Original one	~2 ft^3		Still no flow when pressured to 40 psi. Rain out.			
6/28	2 VN	Original one			Notched to 30 ft from top of flange to bottom.			

N = Notch, F = Fracture, VN = Vertical notch.

			Notch size					
Date	Hole No.	Notching tool	Volume cuttings	Caliper	Comments	Volume slurry	Type slurry	Hole No. connected to
7/6	5 F				Activated No. 24. Broke through. ~30 to 35 psi.	1.1 yd^3	5 to 10% bentonite	24
7/7	3 N	New air line tool						
	3 F				Leak developed 5 ft from casing. Moved to No. 6.	2.2 yd^3		
	6 N	New air line tool			Pressure loss due to hose failure. Ground cave-in. Sealed with oats and grits.			
				20 in. irregular	Recalipered.			
7/8	0 VN	Original one						
	3 N	New air line tool						
	3 F				Connected to perimeter. Stopped pumping.	0.7 yd^3		
7/8					Sealed No. 6 more.			
	3 F				Required 45 psi. Leak developed half way to perimeter.	1.1 yd^3		
7/9					Reloaded perimeter, twice original charge load.			

N = Notch, F = Fracture, VN = Vertical notch.

Date	Hole No.	Notching tool	Notch size		Comments	Volume slurry	Type slurry	Hole No. connected to
			Volume cuttings	Caliper				
7/9	0 N	New air line tool	Small		Notched at 25 ft 6 in. Bubbles in sump. Leak developed 8 ft from casing. Sealing with oats and grits. Good to 45 psi. Renotched. O.K.			
7/10	0 N	New air line tool	~0.8 ft^3					
	0 F				Fractured at 45 psi. Leak developed 8 ft from casing, easily sealed.	1.1 yd^3	6% bentonite	
	0 F				Resealed twice.			
	0 N				Renotched with high spurt		High spirt	
7/10					Intermediate holes pressured. No. 6 leaked.			
7/13	0			12 to 14 in. radially	Calipered center hole, at 25 ft 8 in. depth.			
	0 N	New yellow jetter	~4 ft^3		New jet notcher at site. Jet pressure 125 to 150 psi. Air pressure 10 psi.		2% bentonite	
	0 F				Leak half way to No. 2. Sealed with oats and grits.		Oats and grits	
7/14	0 N						benonite mud	

N = Notch, F = Fracture, VN = Vertical notch.

Date	Hole No.	Notching tool	Notch size Volume cuttings	Caliper	Comments	Volume slurry	Type slurry	Hole No. connected to
7/15	0 N		1/2 barrel ($\sim$4 ft^3)		Seal good to 35 psi.		1 to 2% bentonite	
	0 F				Fractured at 25 psi. Slight leak half way to No. 2.	2.2 yd^3	Up to 10% bentonite	
7/15	0 F				Connection to perimeter.			10
	2 F				27 psi, connection.	1.1 yd^3		10
					Perimeter flow now at 10, 17, 7			
					24 hr pumping every 45 min.			
					Lift everywhere but No. 15.			
7/16	0 F				All intermediate holes connected. Perimeter flows at 1, 8, 9, 17, 24.	0.6 yd^3	50/50 mud	
	3 F					0.1 yd^3	50/50 mud	
	3 F					0.1 yd^3	Recycled 10%	
	0, 3 F					0.2 yd^3	Recycled 10%	
7/18	0 F					1.0 yd^3	Heavy plus CMC	
7/17	0, 3 F				(24 hr pumping) Pumping continues.	0.3 yd^3	Recycled plus barite	
7/19	Pumping to all holes				Return yellow jet pump.	1.5 yd^3	Sandy mud	3, 20
7/20	Pumping to all holes, primarily 0, 3				Leak at No. 20. Prepared for second major blast. BLASTED p.m.	7.5 yd^3	Sandy mud	20

N = Notch, F = Fracture, VN = Vertical notch.

Date	Hole No.	Notching tool	Notch size: Volume cuttings	Notch size: Caliper	Comments	Volume slurry	Type slurry	Hole No. connected to
7/21	Pumping to all holes				Leaks plugged with utility poles at No. 7 and No. 20. Leak at No. 1 self-sealed overnight.	8 yd^3		
7/22					Leak at No. 7 resealed. Leak at No. 24 plugged.	8 yd^3		
7/23	Pumping to all holes				Leak at No. 18 plugged.			
	Major at 0, 1, 5 and 6					4-1/2 yd^3	5/2-1/2	
	Mud thickened 5 & 6 plugged				No. 5 and No. 6 plugged. Thick mud leaked from fracture near No. 3.			
7/24	Flow to all but 6					8 yd^3 1-1/2 yd^3	5/3 5/2-1/2	
7/26	Flow to all but 6					10-1/2 yd^3	5/3 plus sand	
7/27	Flow to all but 6				Sonotube No. 9 leaked at end of day.	7-1/2 yd^3	5/3 plus sand	9
7/28	Flow to all but 6					$\sim$4 yd^3	6/2-3/4	

N = Notch, F = Fracture, VN = Vertical notch.

APPENDIX B

LIFT PROCESS SUMMARY AND DAILY RECORD OF DISPLACEMENT

DATE: July 7, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 3 notched, fractured, leak developed		∿2 yd^3 (8 barrels)	
No. 6 notched, hose failure	Oats and grits		

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	0	0	0
1	0	0	0
2	1/32	1/32	1/32
3	5/32	5/32	5/32
4	0	0	0
5	0	0	0
6	0	0	0
7p	0	0	0
10p	0	0	0
15p	1/32	1/32	1/32
18p	0	0	0
3p	0	0	0
22p	0	0	0
25p	0	0	0
30p	0	0	0
14p	0	0	0
R	-	-	-

DATE: July 8, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 0 deepened using vertical jet.			
No. 3		$\sim$1-1/2 yd^3 (6-7 barrels)	

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	0	0	0
1	0	0	0
2	0	1/32	1/32
3	0	5/32	5/32
4	0	0	0
5	0	0	0
6	0	0	0
7p	0	0	0
10p	0	0	0
15p	0	1/32	1/32
18p	0	0	0
3p	0	0	0
22p	0	0	0
25p	0	0	0
30p	0	0	0
14p	0	0	0
R	-	-	-

DATE: July 9, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 0	Oats and grits		
New notching tool			

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	0	0	0
1	0	0	0
2	0	1/32	1/32
3	0	5/32	5/32
4	0	0	0
5	0	0	0
6	0	0	0
7p	0	0	0
10p	0	0	0
15p	0	1/32	1/32
18p	0	0	0
3p	0	0	0
22p	0	0	0
25p	0	0	0
30p	0	0	0
14p	0	0	0
R	-	-	-

DATE: July 10, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 0	6% Bentonite	∿1 yd ^{3} (4 barrels)	
New notching tool			
	High Spurt		

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	1/16	1/16	1/16
1	0	0	0
2	0	1/32	1/32
3	0	5/32	5/32
4	0	0	0
5	1/32	1/32	1/32
6	0	0	0
7p	0	0	0
10p	0	0	0
15p	0	1/32	1/32
18p	0	0	0
3p	0	0	0
22p	0	0	0
25p	1/32	1/32	1/32
30p	0	0	0
14p	0	0	0
R	-	-	-

DATE: July 13, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 0	Oats and grits		
large yellow jetting pump	2% Bentonite		

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	0	1/16	1/16
1	0	0	0
2	0	1/32	1/32
3	0	5/32	5/32
4	0	0	0
5	0	1/32	1/32
6	0	0	0
7p	0	0	0
10p	0	0	0
15p	0	1/32	1/32
18p	0	0	0
3p	0	0	0
22p	0	0	0
25p	0	1/32	1/32
30p	0	0	0
14p	0	0	0
R	-	-	-

DATE: July 14, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 0	Oats and grits	$\sim$1/4 yd^3 (1 barrel)	
large yellow jetting pump	Bentonite slurry		

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	0	1/16	1/16
1	0	0	0
2	0	1/32	1/32
3	0	5/32	5/32
4	0	0	0
5	0	1/32	1/32
6	0	0	0
7p	0	0	0
10p	0	0	0
15p	0	1/32	1/32
18p	0	0	0
3p	0	0	0
22p	0	0	0
25p	0	1/32	1/32
30p	0	0	0
14p	0	0	0
R	-	-	-

DATE: July 15, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 0	10% bent.		
large yellow jetting pump			3-1/4 yd^3 (12 barrels)

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	-	1/16	1/16
1	1/8	1/8	1/8
2	1/4	9/32	9/32
3	1/8	9/32	9/32
4	3/16	3/16	3/16
5	1/8	5/32	5/32
6	1/16	1/16	1/16
7p	1/8	1/8	1/8
10p	1/16	1/16	1/16
15p	0	1/32	1/32
18p	1/16	1/16	1/16
3p	0	0	0
22p	3/32	3/32	3/32
25p	1/16	3/32	3/32
30p	1/16	1/16	1/16
14p	-	0	0
R	-	-	-

DATE: July 16, 1982

Injection hole	Type of mud	Quantity of mud	Total mud

Point	Observed movement RLC (inches)	Total (inches)	Corrected (same as total)
0	1/8	3/16	3/16
1	1/16	3/16	3/16
2	1/8	13/32	13/32
3	1/8	13/32	13/32
4	1/8	5/16	5/16
5	0	5/32	5/32
6	1/16	1/8	1/8
7p	1/16	3/16	3/16
10p	1/16	1/8	1/8
15p	-1/8*	-3/32*	-3/32*
18p	1/8	3/16	3/16
3p	0	0	0
22p	0	3/32	3/32
25p	1/16	5/32	5/32
30p	0	1/16	1/16
14p	-	0	0
R	0	-	-

DATE: July 17,1982

Injection hole	Type of mud	Quantity of mud	Total mud

Point	Observed movement RLC (inches)	Total (inches)	Corrected** (same as total)
0	27/32	1-1/32	1-1/16
1	11/16	7/8	15/16
2	1-1/8	1-17/32	1-21/32
3	7/8	1-9/32	1-13/32
4	7/8	1-3/16	1-5/16
5	5/8	25/32	29/32
6	7/16	9/16	5/8
7p	9/16	3/4	13/16
10p	1/4	3/8	3/8
15p	0	-3/32*	-3/32*
18p	3/4	15/16	1-1/16
3p	7/16	7/16	1/2
22p	5/16	13/32	15/32
25p	1/4	13/32	13/32
30p	5/16	3/8	3/8
14p	0	0	0
R	0	-	-

DATE: July 19, 1982

Injection hole	Type of mud	Quantity of mud	Total mud

Point	Observed movement (inches) TEG	Total (inches)	Corrected ** (same as total)
0	5/16	1-11/32	1-1/16
1	1/4	1-1/8	15/16
2	5/16	1-27/32	1-19/32
3	7/16	1-23/32	1-15/32
4	3/8	1-9/16	1-5/16
5	1/4	1-1/32	27/32
6	1/4	13/16	5/8
7p	3/16	15/16	13/16
10p	1/16	7/16	3/8
15p	0	-3/32*	-3/32*
18p	3/8	1-5/16	1-1/16
3p	3/16	5/8	1/2
22p	1/8	17/32	13/32
25p	1/16	15/32	11/32
30p	3/16	9/16	3/8
14p	0	0	1/32
R	0	-	-

DATE: July 20, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
Injecting at No. 3 during blast		1-1/2 yd ^{3}	1-1/2 yd ^{3} (+ heavy mud?)

Point	Observed movement TEG (inches)	Total (inches)	Corrected (same as total)
0	3/16	1-17/32	1-14/32
1	1/8	1-1/4	1-1/4
2	5/16	2-5/32	2-7/32
3	3/8	2-3/32	1-25/32
4	5/16	1-7/8	1-3/4
5	1/8	1-5/32	1-5/32
6	1/16	7/8	7/8
7p	1/16	1	1-5/16
10p	0	7/16	3/8
15p	-1/16*	-5/32*	-5/32*
18p	1/4	1-9/16	1-11/16
3p	0	5/8	5/8
22p	1/16	19/32	15/32
25p	1/16	17/32	17/32
30p	1/16	5/8	11/16
14p	-3/32*	-3/32*	1/16
R	0	-	-

DATE: July 21, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
			8 yd^3

Point	Observed movement TEG (inches)	Total (inches)	Corrected (same as total)
0	1/4	1-25/32	1-13/16
1	5/16	1-9/16	1-9/16
2	7/16	2-19/32	2-25/32
3	3/8	2-15/32	2-7/32
4	1/4	2-1/8	2-1/8
5	5/32	1-5/16	1-3/8
6	1/8	1	1-1/16
7p	1/4	1-1/4	1-5/8
10p	0	7/16	7/16
15p	-1/32*	-3/16*	-3/16*
18p	1/8	1-11/16	1-7/8
3p	1/8	3/4	13/16
22p	1/8	23/32	19/32
25p	1/16	19/32	19/32
30p	1/16	11/16	3/4
14p	-1/32*	-1/8*	1/16
R	0	-	-

DATE: July 22, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
			8 yd^3 (+ heavy mud?)

Point	Observed movement (inches)	Total (inches)	Corrected (same as total)
0	13/16	2-19/32	2-9/16
1	9/16	2-1/8	2-1/16
2	1-3/8	3-31/32	4-1/32
3	15/16	3-13/32	3-1/32
4	1-1/16	3-3/16	3-1/16
5	9/16	1-7/8	1-29/32
6	7/16	1-7/16	1-3/8
7p	1/2	1-3/4	2-1/16
10p	1/8	9/16	1/2
15p	0	-3/16*	-3/16*
18p	13/16	2-1/2	2-5/8
3p	1/4	1	1-1/16
22p	5/16	1-1/32	27/32
25p	3/16	25/32	23/32
30p	3/16	7/8	7/8
14p	-1/32*	-5/32*	1/32
R	0	-	-

DATE: July 23, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
Initially, flow to all holes			
Sand dried out. Mud thickened Unable to pump to No. 5 and No. 6.	(5/2-1/2)	4-1/2 yd^3	4-1/2 yd^3
Major injections throughout day at holes No. 0, No. 1, No. 5 and No. 6 until plugs at No. 5 and No. 6			
Thick mud leaked by hole No. 3 fracture			

Point	Observed movement TEG (inches)	Total (inches)	Corrected (same as total)
0	1-1/4	3-27/32	3-15/16
1	11/16	2-13/16	2-13/16
2	1-13/16	5-25/32	5-27/32
3	7/8	4-9/32	3-29/32
4	1-15/16	5-1/8	5
5	1-1/16	2-15/16	2-31/32
6	1/2	1-15/16	1-7/8
7p	11/16	2-7/16	2-1/16
10p	0	9/16	1/2
15p	-1/16*	-1/4*	-1/4*
18p	1-1/4	3-3/4	4
3p	3/8	1-3/8	1-1/2
22p	7/8	1-29/32	1-25/32
25p	5/8	1-13/32	1-11/32
30p	1/4	1-1/8	1-3/16
14p	0	-5/32*	1/16
R	0	-	-

DATE: July 24, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
Flow at all but No. 6 hole	(5/3)	8 yd^3	9-1/2 yd^3
Major injections at holes No. 0, No. 1 and No. 5	(5/2-1/2)	1-1/2 yd^3	
Mud thickened at midday, we added some H_2O			

Point	Observed movement TEG (inches)	Total (inches)	Corrected (same as total)
0	1-9/16	5-13/32	5-1/2
1	7/8	3-11/16	3-11/16
2	1-7/8	7-21/32	7-23/32
3	3/4	5-1/32	4-21/32
4	2-3/8	7-1/2	7-3/8
5	1-1/2	4-7/16	4-15/32
6	11/16	2-5/8	2-9/16
7p	7/8	3-5/16	2-15/16
10p	0	9/16	1/2
15p	0	-7/32*	-5/32*
18p	3/16	3-15/16	4-3/16
3p	3/16	1-9/16	1-11/16
22p	1-1/16	2-31/32	2-27/32
25p	7/8	2-9/32	2-7/32
30p	3/8	1-1/2	1-9/16
14p	1/16	-3/32*	5/32
R	0	-	-

DATE: July 26, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
Flow verified at all but hole No. 6			
Major injections at holes No. 0, No. 1 and No. 5	Sand and % bentonite	10-1/2 yd^3	10-1/2 yd^3
Major lifts observed at holes No. 2 and No. 4	(5/3) 5 buckets bentonite 3 barrels H_2O		

Point	Observed movement TEG (inches)	Total (inches)	Corrected (same as total)
0	1-5/8	7-1/32	6-7/8
1	1-3/16	4-7/8	4-3/4
2	2-1/8	9-25/32	9-19/32
3	1-9/16	6-19/32	6-1/32
4	2-1/16	9-9/16	9-1/4
5	1-7/16	5-7/8	5-23/32
6	7/8	3-1/2	3-5/16
7p	1-1/8	4-7/16	4-3/16
10p	1/16	5/8	1/2
15p	1/16	-5/32*	-5/32*
18p	3/8	4-5/16	4-3/16
3p	11/16	2-1/4	2-3/8
22p	5/16	3-9/32	3-1/32
25p	11/16	2-31/32	2-17/32
30p	1/2	2	2
14p	3/32	0	5/32
R	0	-	-

DATE: July 27, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 6 still plugged			7-1/2 yd^3

Point	Observed movement RBH (inches)	Total (inches)	Corrected (same as total)
0			
0	3/4	7-1/32	
1	5/8	5-1/2	
2	1-1/16	10-27/32	
3	1/8	6-23/32	
4	7/8	9-9/16	
5	5/8	5-7/8	
6	3/8	3-1/2	
7p	3/8	4-7/16	
10p	13/16	1-3/8	
15p	0	-5/32*	
18p	5/32	4-5/16	
3p	3/8	2-5/8	
22p	-1/16	3-9/32	
25p	3/16	2-31/32	
30p	1/4	2-1/4	
14p	0	0	
R	0	-	
3A	5/8	5/8	

DATE: July 28, 1982

Injection hole	Type of mud	Quantity of mud	Total mud
No. 6 still plugged			
Major injections at hole No. 1 and No. 5	(6/2-3/4)		4-1/2 yd^3
Flow verified at No. 3 and No. 4			

Point	Observed movement RBH (inches)	Total (inches)	Corrected (same as total)
0	3/8	7-5/32	
1	5/16	5-9/16	
2	3/4	10-31/32	
3	3/16	7-1/32	
4	9/16	9-5/8	
5	4/16	5-15/16	
6	3/16	3-1/2	
7p	-1/16	4-7/16	
10p	10/16	1-3/8	
15p	0	-5/32*	
18p	1/16	4-5/16	
3p	4/16	2-5/8	
22p	0	3-9/32	
25p	3/16	2-31/32	
30p	3/16	2-1/4	
14p	0	0	
R	0	-	
3A	13/16	13/16	

DATE: July 29, 1982

Injection hole	Type of mud	Quantity of mud	Total mud

Point	Observed movement RBH (inches)	Total (inches)	Corrected (same as total)
0	11/16	7-27/32	
1	1/2	6-1/16	
2	1-3/16	12-5/32	
3	0	7-1/32	
4	3/4	10-3/8	
5	7/16	6-3/8	
6	1/4	3-3/4	
7p	7/16	4-7/8	
10p	1-1/2	2-7/8	
15p	1/16	-3/32*	
18p	1/8	4-7/16	
3p	5/16	2-15/16	
22p	1/16	3-11/32	
25p	1/8	3-3/32	
30p	1/16	2-5/16	
14p	0	0	
R	0	-	
3A	1-1/8	1-15/16	

DATE: July 30, 1982

Injection hole	Type of mud	Quantity of mud	Total mud

Point	Observed movement RBH	Total	Corrected (same as total)
0			
1			
2	Only recorded movement is overnight settlement; average of ∿3/32 in.		
3			
4			
5			
6			
7p			
10p			
15p			
18p			
3p			
22p			
25p			
30p			
14p			
R			

DATE: July 31, 1982

Injection hole	Type of mud	Quantity of mud	Total mud

Point	Observed movement RBH	Total	Corrected (inches)
0			8.13
1			5.69
2			12.03
3	Average overnight block settlement of ∿3/32 in.		8.03
4			11.00
5			6.66
6			3.81
7p			4.94
10p			0.94
15p			-0.22
18p			4.22
3p			3.00
22p			2.78
25p			2.84
30p			2.25
14p			0.03
R			

APPENDIX C

BLASTING REPORT

MURRAY D. BLACK CO., INC.
GENERAL AND MARINE CONTRACTORS

1919 BEACHWAY ROAD
SUITE 5R
JACKSONVILLE, FLORIDA 32207
TELEPHONE (904) 398 5112

8 June 1982

Foster-Miller Associates, Inc.
350 Second Avenue
Waltham, MA 02154

Attn: Mr. Thomas Gore, Project Engineer

RE: WHITEHOUSE PROJECT

First blast at 08:09 A.M. - shot one (1) hole for effect.
Bottom-up shooting
Mud level constant
Very slight mud splatter from top of sona-tube. No damage to sona-tube.

Second blast at 8:38 P.M.
The following holes were shot high. Not able to reach total depth due to hole caving, bridging, deviation of loading pipe, etc.

Hole	# 3	8"	High
	# 4	2'	High
	#17	6'	High
	#24	1'	High
	#26	12'	High
	#27	4'	High
	#29	4'	High
	#31	3'	High

Misfire occurred on four holes. Primarily due to very large number of splices in firing circuit. The following holes misfired:

5
#22
#28
#31

Attempted to re-shoot misfires at 8:52 P.M. Results were negative.

Results of blast will be detailed by Mr. Brunsing.

Respectfully yours,

Murray D. Black

Murray D. Black

MDB/fk

cc: Mr. Thomas P. Brunsing
Project Engineer

MURRAY D. BLACK CO., INC.
GENERAL AND MARINE CONTRACTORS

1919 BEACHWAY ROAD
SUITE 5K
JACKSONVILLE FLORIDA 32207
TELEPHONE (904) 399 5132

May 4, 1982

ATTN: Mr Thomas P. Brunsing
Project Engineer

TO: Foster-Miller Associates, Inc.
350 Second Avenue
Wlatham, Mass. 02154

"Whitehouse Project" 30 April 1982

N. B. unless otherwise noted only the following products were utilized:

Atlas Rockmaster Caps
W/60' Leg Wires
Ensign Bickford Primacord
Reinforced 50 Gr. Per Foot

Arrived on Job Site at 7:25 AM

Made up three (3) 45' Det Cords

1st Shot at 0854 AM

Buried Det Cord 4' in hole, then under sona-tube. Mud blew out top of sona-tube. Split bottom of sona-tube (6").

10' Det Cord. 1 Cap

2nd Shot at 0930 AM

As in 1st shot, Det Cord and cap were buried 8" in ground. Noise and vibration were very low level. Very little mud blown form sona-tube.

15' Det Cord 1 Cap

3rd Shot at 1105 AM

Ran Det Cord out of top of sona-tube. Considerably more noise. Actually, noise level would not be acceptable for multiple shots. Split sona-tube along entire length.

25' Det Cord 1 Cap

4th Shot at 1225 PM

Det Cord tied to lath 1' below grade. Also Det Cord ran through copper tubing (½" x 2') under sona-tube. On firing the copper tubing was vaporized, and sona-tube ruptured severely. Very little noise. No mud blown form sona-tube.

15' Det Cord 1 Cap

5th Shot at 505 PM

3 holes shot - holes are 27' deep on 14° (fourteen degree) angle, 6" in diameter W/6" shots ½" wide on each side of each hole. Holes were shot from bottom up W/10' overlap of Det Cord on bottom. Parallel hook-up and fired instantaneously. Top of Det Cord was suspended (with minor tension) in middle of hole, 1' below bottom of sona-tube. Sona-tubes were topped off with mud.

Shot blew fair quantity of mud out of all three holes, and mud level ended up being below water table. (approximately 18"-24")

135" Det Cord 3 Caps

Blaster: Murray D. Black
Powder Monkey: Paul Douglas

Under Direction of: Thomas P. Brunsing

Cleaned up and secured job site
Left job site 610PM

MURRAY D BLACK CO INC

MURRAY D. BLACK CO., INC.
GENERAL AND MARINE CONTRACTORS

1919 BEACHWAY ROAD
SUITE 5K
JACKSONVILLE, FLORIDA 32207
TELEPHONE (904) 398-5112

WHITEHOUSE PROJECT

FOSTER-MILLER ASSOCIATES, INC.

CONTRACT LOG

July 20, 1982

9:00 A.M.	Load equipment and explosives in Jacksonville.
10:00 A.M.	Arrive job site. Begin preparing shot.
02:30 P.M.	Complete shot preparation. Wait for engineers to complete hose hook-up.
02:50 P.M.	Engineers give "go ahead" for capping off.
03:10 P.M.	Round fired.
03:20 P.M.	Completed inspection of 32 holes. All holes fired (See shot log).
03:30	Left job site.

MURRAY D. BLACK CO., INC.
GENERAL AND MARINE CONTRACTORS

1919 BEACHWAY ROAD
SUITE 5K
JACKSONVILLE, FLORIDA 32207
TELEPHONE (904) 398 5132

WHITEHOUSE PROJECT

SHOT LOG - JULY 20, 1982

N.B. T.D. means Total Depth reached. In the Sona-tubes (S) the project cap setting depth was -14'. In the PVC pipes (PVC) the project cap setting depth was - 9', except in hole #4 where there was 6' (more or less) OF PVC pipe in the hole and the project cap setting depth was -13'.

HOLE #

1 - TD (S)
2 - 3' high (PVC)
3 - TD (S)
4 - 3' high (PVC)
5 - TD (S)
6 - TD (S)
7 - TD (S)
8 - TD (S)
9 - TD (S)
10 - 3' high (S)
11 - T.D. (S)
12 - TD (PVC)
13 - TD (PVC)
14 - TD (S)
15 - TD (S)
16 - TD (S)
17 - TD (S)
18 - TD (S)
19 - TD (S)
20 - TD (PVC)
21 - TD (PVC)
22 - TD (S)
23 - TD (S)
24 - TD (S)
25 - TD (S)
26 - TD (S)
27 - TD (S)
28 - TD (PVC)
29 - 3' High (S)
30 - 3' High (S)
31 - TD (S)
32 - TD (S)

MURRAY D. BLACK CO., INC.
GENERAL AND MARINE CONTRACTORS

1919 BEACHWAY ROAD
SUITE 5K
JACKSONVILLE, FLORIDA 32207
TELEPHONE (904) 398-5112

WHITEHOUSE PROJECT

SHOT LOG - JULY 9, 1982

HOLE #

1 - T.D.*(Redrill)
2 - T.D. (Redrill)
3 - 1' High
4 - T.D.
5 - Lost Bottom 10' of running tool (aluminum Rod) in hole. Made-up new running tool of PVC Pipe. T.D.
6 - T.D.
7 - 1.5' High
8 - T.D.
9 - T.D.
10 - T.D.
11 - T.D.
12 - T.D.
13 - T.D.
14 - T.D.
15 - T.D.
16 - T.D.
17 - T.D.
18 - 4' High (Redrilled Twice!)
19 - T.D.
20 - T.D.
21 - 3' (Redrilled Twice)
22 - T.D.
23 - T.D.
24 - 1.5' High
25 - 1' High
26 - T.D. (Redrill)
27 - 5.5' High (Redrill - unable to dig deeper than 21.5') Was 4' high on previous sho
28 - Broke leg wires on previous shot. Able to recap and shoot from top down. 1,850 Grains total loading.
29 - 3' High
30 - 1.5' High - Broke PVC - Repaired same
31 - T.D.
32 - T.D.

* NOTE: T.D. means Total Depth reached, or 27'/

APPENDIX D

INDEPENDENT SITE LAND SURVEY

Map of part of Section 13, Township 2 South, Range 24 East, Duval County, Florida.

Scale: 1"=10'

July 28, 1982

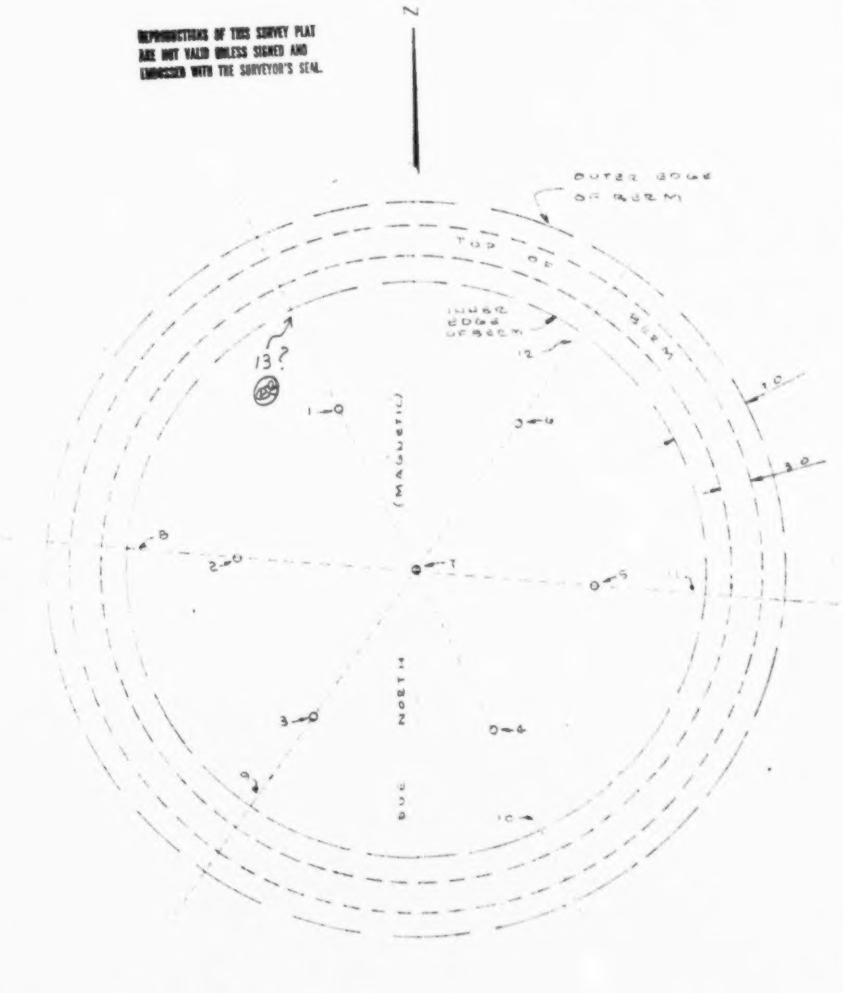
For: Foster-Miller Assoc.

Ellis, Curtis and Konker, Inc.
Land Surveyors and Planners
211 Guaranty Life Bldg.
Jacksonville, Florida 32202

I hereby certify that the information shown hereon is true and correct to the best of my knowledge and belief.

Ted A. Puff, R.L.S. No. 1114
State of Florida

REPRODUCTIONS OF THIS SURVEY PLAT ARE NOT VALID UNLESS SIGNED AND EMBOSSED WITH THE SURVEYOR'S SEAL.


N
OUTER EDGE OF BERM
TOP OF BERM
INNER EDGE OF BERM
13?
12
1.0
3.0
(MAGNETIC)
DUE NORTH
1
2
3
4
5
6
7
8
9
10
11

77094-S-F476-131 [illegible]

TED A. RUFF NO. 1114

ELLIS, CURTIS & KOOKER, INC.
LAND SURVEYORS AND PLANNERS
811 GUARANTY LIFE BUILDING
137 E. FORSYTH STREET
JACKSONVILLE, FLORIDA 32202

PHONE 353-5856
353-5877
AREA CODE 904

July 28, 1982

The difference in elevation shown on the attatched map and referenced below shows the increase in elevation at the points so referenced.

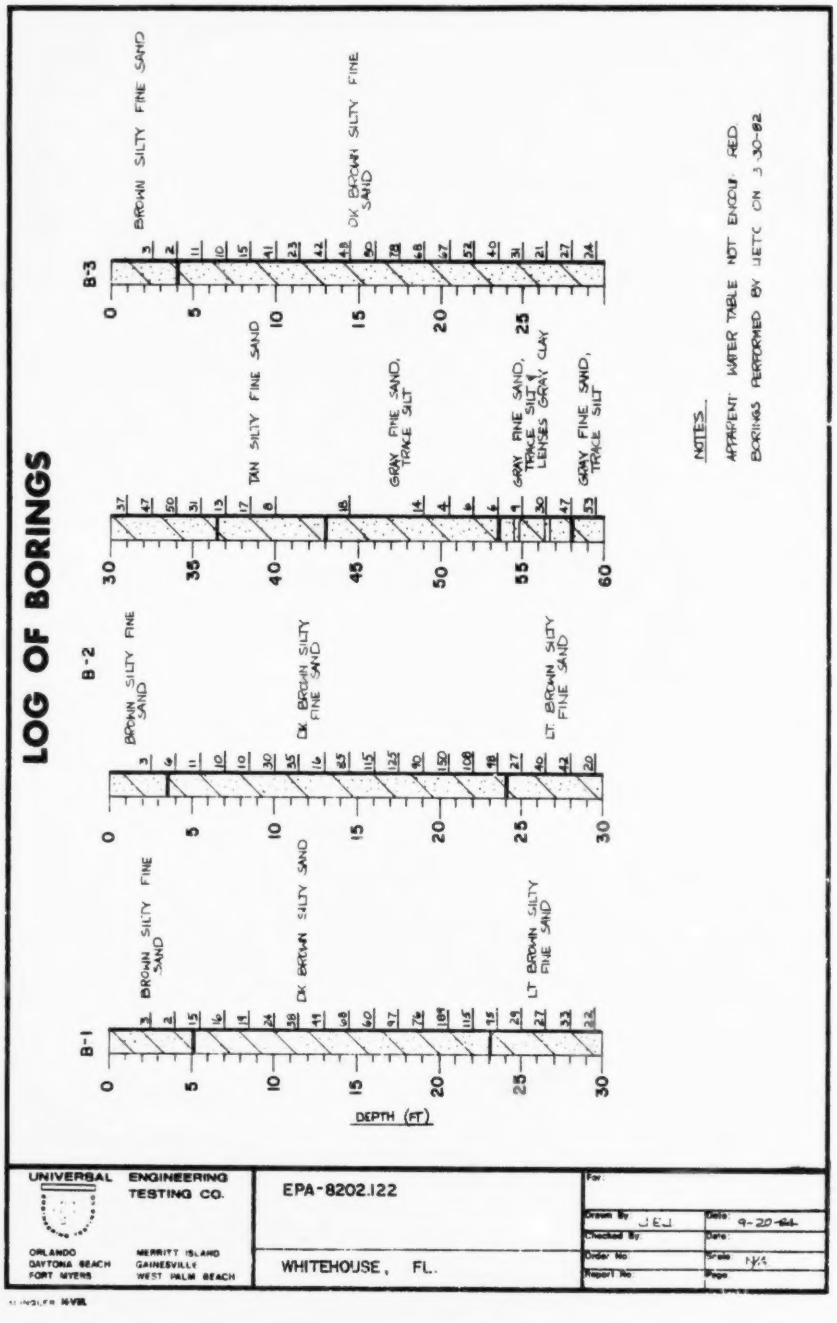
REFERENCE POINT	DIFFERENCE IN ELEVATION
1	+ 5/16"
2	+ 3/4"
3	+ 3/4"
4	+ 5/8"
5	+ 3/8"
6	+ 3/16"
7	0"
8	+ 5/8"
9	0"
10	+ 1/8"
11	+ 1/16"
12	+ 1/16"
13	+ 3/16"

The above differences in elevation reflect the amount of rise from elevations taken between 8:23 A.M. and 12:50 P.M. on July 28, 1982.

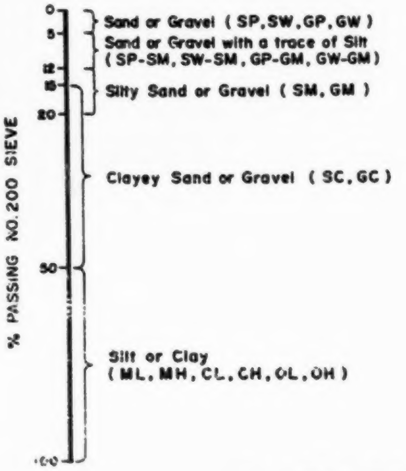
Ted A. Ruff
Ted A. Ruff, R.L.S. No. 1114
State of Florida

APPENDIX E

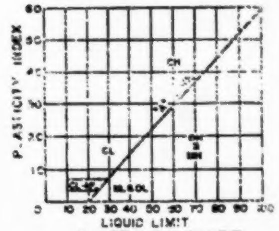
PRELIMINARY GEOTECHNICAL SITE INVESTIGATION
TEST WELL CORE LOG DATA


LOG OF BORINGS
B-1
BROWN SILTY FINE SAND
DK BROWN SILTY SAND
LT BROWN SILTY FINE SAND
B-2
BROWN SILTY FINE SAND
DK BROWN SILTY FINE SAND
LT. BROWN SILTY FINE SAND
TAN SILTY FINE SAND
GRAY FINE SAND, TRACE SILT
GRAY FINE SAND, TRACE SILT & LENSES GRAY CLAY
GRAY FINE SAND, TRACE SILT
B-3
BROWN SILTY FINE SAND
DK BROWN SILTY FINE SAND
DEPTH (FT)
NOTES
APPARENT WATER TABLE NOT ENCOUNTERED
BORINGS PERFORMED BY UETC ON 3-30-82
UNIVERSAL ENGINEERING TESTING CO.
ORLANDO
DAYTONA BEACH
FORT MYERS
MERRITT ISLAND
GAINESVILLE
WEST PALM BEACH
EPA-8202.122
WHITEHOUSE, FL.
For:
Drawn By: JEJ
Date: 9-20-84
Checked By:
Date:
Order No:
Scale: N/A
Report No:
Page:

SOILS CLASSIFICATION CHART

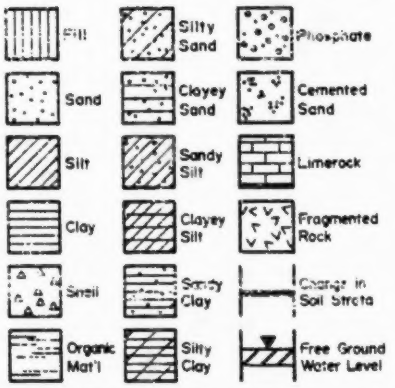

% PASSING NO.200 SIEVE
0
5
12
15
20
50
100
Sand or Gravel (SP, SW, GP, GW)
Sand or Gravel with a trace of Silt (SP-SM, SW-SM, GP-GM, GW-GM)
Silty Sand or Gravel (SM, GM)
Clayey Sand or Gravel (SC, GC)
Silt or Clay (ML, MH, CL, CH, OL, OH)

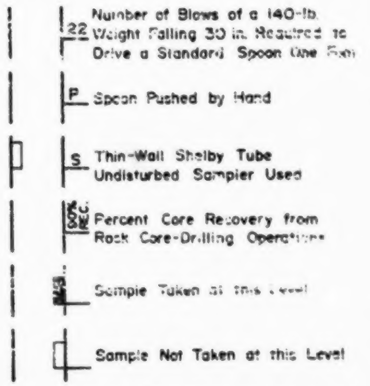
UNIVERSAL ENGINEERING TESTING CO.



PLASTICITY CHART

KEY TO BORING LOGS


Fill
Sand
Silt
Clay
Shell
Organic Mat'l
Silty Sand
Clayey Sand
Sandy Silt
Clayey Silt
Sandy Clay
Silty Clay
Phosphate
Cemented Sand
Limerock
Fragmented Rock
Change in Soil Strata
Free Ground Water Level



Number of Blows of a 140-lb. Weight Falling 30 in. Required to Drive a Standard Spoon One Foot

Spoon Pushed by Hand

Thin-Wall Shelby Tube Undisturbed Sampler Used

Percent Core Recovery from Rock Core-Drilling Operations

Sample Taken at this Level

Sample Not Taken at this Level

RELATIVE DENSITY (sand-silt)

Very Loose - Less Than 4 Blows/Ft.
Loose - 4 to 10 Blows/Ft.
Medium - 10 to 30 Blows/Ft.
Dense - 30 to 50 Blows/Ft.
Very Dense - More Than 50 Blows/Ft.

CONSISTENCY (clay)

Very Soft - Less Than 2 Blows/Ft
Soft - 2 to 4 Blows/Ft.
Medium - 4 to 8 Blows/Ft
Stiff - 8 to 15 Blows/Ft
Very Stiff - 15 to 30 Blows/Ft.
Hard - More Than 30 Blows/Ft.

LABORATORY TESTING SUMMARY

Specimen No.	Test Hole No.	Depth (ft)	Description	Tests reported: Density	Tests reported: Permeability	Tests reported: Sieve Analysis
1-1	1	7	Gray sand with silt	x	–	–
1-2	1	12	Dark brown sand with silt	x	x	–
1-4	1	20.5	Dark red-brown sand with silt	–	x	–
1-6	1	27.5	Brown sand	x	x	x
2-1	2	20	Red-brown sand with silt	x	x	–
2-3	2	9	Black sandy silt	–	–	x

Data from these test reports follow.

LABORATORY TEST DATA

Specimen No. 1 Test Hole 1

Date 4/7/82

Depth 7 ft

Description: Gray sand with traces of silt

Density

Compaction	γ_d (lb/ft^3)	Sample height (cm)	Sample diameter (cm)	Area (cm^2)	Volume (cm^3)	WWS (g)	WDS (g)	Weight H_2O (g)	MC (%)
In situ	-	-	-	-	-	-	-	-	-
Loose	84	7.8	3.5	9.62	75.04	-	101.0	-	-
Tight	113.6	9.1	3.5	9.62	87.54	175.9	159.3	16.6	10.4

Permeability

Test No.	Sample length (cm)	Time (sec)	Head Begin	Head End	Sample volume (cm^3)	Dry density (lb/ft^3)	Permeability (k-cm/sec)
1	-	-	14.9	-	-	-	-
2	-	-	-	-	-	-	-

Sieve Analysis

Total weight of dry soil ________________

Weight of soil after wash ________________

Sieve size	Cumulative weight (g)	Percent retained	Percent passing
3			
3/4			
4			
10			
40			
60			
100			
200			

LABORATORY TEST DATA

Specimen No. 2 Test Hole 1 Date 4/7/82
Depth 12 ft
Description: Dark brown sand with traces of silt (HP type)

Density

Compaction	γ_d (lb/ft^3)	Sample height (cm)	Sample diameter (cm)	Area (cm^2)	Volume (cm^3)	WWS (g)	WDS (g)	Weight H_2O (g)	MC (%)
In situ	98.9	2.5	3.5	9.62	24.05	44.0	38.1	5.9	15.5
Loose	68.9	7.8	3.5	9.62	75.04	-	82.9	-	-
Tight	98.0	6.6	3.5	9.62	63.49	116.1	99.7	16.4	16.4

Permeability

Test No.	Sample length (cm)	Time (sec)	Head Begin	Head End	Sample volume (cm^3)	Dry density (lb/ft^3)	Permeability (k-cm/sec)
1	8.4	900	14.9	13.8	80.81	91.2	7.15×10^{-4}
2	8.4	2280	14.9	14.3	80.81	91.2	1.51×10^{-4}

Sieve Analysis

Total weight of dry soil ________________
Weight of soil after wash ________________

Sieve size	Cumulative weight (g)	Percent retained	Percent passing
3			
3/4			
4			
10			
40			
60			
100			
200			

LABORATORY TEST DATA

Date 4/7/82
Specimen No. 4 Test Hole 1 Depth 20.5 ft
Description: Dark red/brown sand with traces of silt

Density

Compaction	γ_d (lb/ft^3)	Sample height (cm)	Sample diameter (cm)	Area (cm^2)	Volume (cm^3)	WWS (g)	WDS (g)	Weight H_2O (g)	MC (%)
In situ									
Loose									
Tight									

Permeability

Test No.	Sample length (cm)	Time (sec)	Head Begin	Head End	Sample volume (cm^3)	Dry density (lb/ft^3)	Permeability (k-cm/sec)
1	9.2	600	14.9	14.2	88.50	98.2	7.37×10^{-4}
2	9.2	1500	14.9	13.2	88.50	98.2	7.42×10^{-4}

Sieve Analysis

Total weight of dry soil ________________
Weight of soil after wash ________________

Sieve size	Cumulative weight (g)	Percent retained	Percent passing
3			
3/4			
4			
10			
40			
60			
100			
200			

LABORATORY TEST DATA

Date 4/7/82
Specimen No. 1 Test Hole 2 Depth 20 ft
Description: Red brown sand with traces of silt (HP type)

Density

Compaction	γ_d (lb/ft^3)	Sample height (cm)	Sample diameter (cm)	Area (cm^2)	Volume (cm^3)	WWS (g)	WDS (g)	Weight H_2O (g)	Weight MC (%)
In situ	78.9	3.7	3.5	9.62	35.59	49.0	45.0	4.0	8.9
Loose	76.2	7.8	3.5	9.62	75.04	-	91.6	-	-
Tight	96.2	8.3	3.5	9.62	79.85	132.0	123.1	8.9	7.2

Permeability

Test No.	Sample length (cm)	Time (sec)	Head Begin	Head End	Sample volume (cm^3)	Dry density (lb/ft^3)	Permeability (k-cm/sec)
1	8 8	660	14.9	13.7	84.66	92.4	1.12×10^{-4}
2	8.8	2880	14.9	10.3	84.66	92.4	1.13×10^{-3}

Sieve Analysis

Total weight of dry soil ________________
Weight of soil after wash ________________

Sieve size	Cumulative weight (g)	Percent retained	Percent passing
3			
3/4			
4			
10			
40			
60			
100			
200			

LABORATORY TEST DATA

Date 4/7/82
Depth 27.5 ft

Specimen No. 6 Test Hole 1
Description: Brown sand

Density

Compaction	γ_d (lb/ft^3)	Sample height (cm)	Sample diameter (cm)	Area (cm^2)	Volume (cm^3)	WWS (g)	WDS (g)	Weight H_2O (g)	MC (%)
In situ	–	–	–	–	–	–	–	–	–
Loose	76.5	7.8	3.5	9.62	75.04	–	92.0	–	–
Tight	102.3	8.6	3.5	9.62	82.73	163.0	135.6	27.4	20.2

Permeability

Test No.	Sample length (cm)	Time (sec)	Head Begin	Head End	Sample volume (cm^3)	Dry density (lb/ft^3)	Permeability (k-cm/sec)
1	9.4	720	14.9	13.6	90.43	95.2	1.19×10^{-3}
2	9.4	1560	14.9	12.3	90.43	95.2	1.15×10^{-3}

Sieve Analysis

Total weight of dry soil 200.0g
Weight of soil after wash 191.4g

Sieve size	Cumulative weight (g)	Percent retained	Percent passing
3	0	0	100
3/4	0	0	100
4	0	0	100
10	0.5	0.3	99.7
40	1.5	0.8	99.2
60	6.6	3.3	96.7
100	114.9	57.5	42.5
200	189.3	94.7	5.3

LABORATORY TEST DATA

Date 4/7/82

Specimen No. 3

Test Hole 2

Depth

Description: Dark brown sand with traces of silt

Density

Compaction	γ_d (lb/ft^3)	Sample height (cm)	Sample diameter (cm)	Area (cm^2)	Volume (cm^3)	WWS (g)	WDS (g)	Weight H_2O (g)	MC (%)
In situ									
Loose									
Tight									

Permeability

Test No.	Sample length (cm)	Time (sec)	Head		Sample volume (cm^3)	Dry density (lb/ft^3)	Permeability (k-cm/sec)
			Begin	End			
1							
2							

Sieve Analysis

Total weight of dry soil 200.0g

Weight of soil after wash 180.1g

Sieve size	Cumulative weight (g)	Percent retained	Percent passing
3	0	0	100
3/4	0	0	100
4	0	0	100
10	0	0	100
40	1.1	0.6	99.4
60	22.5	11.3	88.7
100	156.1	78.1	21.9
200	178.2	89.1	10.9

APPENDIX F

UNIT CONVERSIONS

Unit cited in report	Equivalent unit
Length	
cm	0.394 in.
in.	2.54 cm
ft	0.3048m
m	3.281 ft
Mass (weight)	
lb	0.454 kg
grain	0.0648g
Area	
cm^2	0.155 in.^{2}
in.^{2}	6.452 cm^2
ft^2	0.0929 m^2
m^2	10.76 ft^2
Volume	
cm^3	0.06102 in.^{3}
in.^{3}	16.39 cm^3
ft^3	0.02832 m^3
m^3	35.31 ft^3
yd^3	0.7646 m^3
gallon	0.1339 ft^3
gallon	0.00379 m^3
ml	0.06102 in.^{3}
ml	0.0338 fl oz
Pressure	
psi	6895 Pa
Pa	0.000145 psi